Alberta Domestic Well Water Quality Monitoring and Assessment Program

Domestic Well Water Quality in the Beaver River Basin

Drinking Water Quality and Human Health Assessment

Physical & Chemical Testing

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EXECUTIVE SUMMARY

Under the framework of the Alberta *Water for Life Strategy* to ensure safe drinking water for all Albertans, Alberta Health initiated a domestic well water quality monitoring and human health assessment program in Alberta in 2009. The first project was completed in August of 2010 to overview the domestic well quality between 2002 and 2008 in all regions of Alberta. The Beaver River Basin region was selected for follow-up domestic well water quality monitoring and human exposure assessment in 2009.

Evidence of arsenic in well water had been gathered in a 1999-2000 in the Beaver River Basin region. In 2006 the maximum acceptable concentration for arsenic under the *Canadian Drinking Water Guideline for Arsenic* was reduced from 25 µg/L to 10 µg/L. Local residents continued to express concern about arsenic and more recently, uranium in the well water. Consequently, Alberta Health conducted this follow-up survey in order to provide more detailed information on domestic well water quality for well owners and assist them in making decisions as to how to improve well water quality.

The objectives of this follow-up survey include:

1. assessing long-term suitability of domestic well water quality for well owners by monitoring physical properties and chemical concentrations in raw and treated domestic well water samples and comparing the chemical levels to both aesthetic quality-based and health-based guidelines;
2. assessing exposure to chemicals relevant to human health in domestic well water by collecting information on drinking water consumption patterns and calculating daily chemical intake;
3. assessing human health risk from exposure to arsenic in drinking water by comparing exposure intake and health effect information in the literatures;
4. assisting well owners to improve well water quality by providing them with the information about well maintenance and water treatment strategies to domestic well owners; and
5. building information and better understanding of domestic well water quality in specific regions of the province.

The major findings are summarized below:

Untreated domestic well water

1. suitability of domestic water quality for human use by measuring pH, alkalinity, conductivity and TDS was similar in the Beaver River Basin region to suitability in other regions of Alberta;
2. aesthetic water quality by measuring iron, chloride and sulfate was slightly under average level in Alberta;

3. well water was very hard in the Beaver River Basin region compared to water classified as “medium hard or hard” in Alberta;
4. the average sodium level was lower than average levels in other regions of Alberta; and
5. the levels of fluoride, nitrate/nitrite, antimony, barium, boron, cadmium, chromium, lead, mercury, molybdenum, nickel, selenium, uranium and uranium were under the health-based guidelines for 95 to 100 per cent of raw water samples.

Treated domestic well water

1. treatment methods included using softeners, iron filters, reverse osmosis, distillers, activated carbon filters, and chlorinators;
2. alkalinity, conductivity, TDS and bicarbonate were significantly removed by using a combination of treatment methods;
3. hardness was significantly reduced after water treatment, and very hard water became soft water in 80 per cent of houses after using softeners; and
4. sodium or potassium levels were significantly increased after using softeners in some houses, depending on the type of softening chemicals used.

Special issue: arsenic

1. arsenic levels satisfied the health guideline value in 52 per cent of raw water samples and 71 per cent of treated water samples;
2. arsenic levels did not significantly change between 1999 and 2009;
3. arsenic levels were higher in the region than the average level in Alberta;
4. the major arsenic species in well water were inorganic arsenic III and V;
5. arsenic levels were significantly reduced after water treatment, particularly by using reverse osmosis and distiller;
6. 15 per cent of participants consumed water containing arsenic level greater than the health guideline level of 0.01 mg/L; and
7. a daily intake of arsenic from drinking well water for 19 participants who consumed water with arsenic level greater than 0.01 mg/L was averaged 0.0007 mg/kg body weight per day.

Human health assessment

1. 79 per cent of participants treated domestic well water for household use such as using for daily drinking (70 per cent) and for cooking, food preparation, bathing/showering and laundry (over 90 per cent);
2. there may be an increase of potential health risk for cardiovascular health effects if private well owners consume soft water containing very low levels of calcium and magnesium, or very high levels of sodium and potassium resulting from using softeners for a long time; and

3. potential health risk resulting from drinking arsenic-containing water at current measured levels was estimated to be low.

Recommendations are that:

1. private well owners should be advised to test the well water quality regularly, particularly if the arsenic levels exceed the Canadian Drinking Water Quality guideline or sodium and potassium levels are too high;
2. private well owners should be encouraged to select efficient treatment methods or choose alternative drinking water sources to minimize exposure to arsenic via drinking well water as much as possible even though health risk resulting from drinking arsenic containing water was estimated to be low;
3. private well owners should be encouraged to have appropriate maintenance of treatment devices to efficiently reduce the levels of chemicals including arsenic to satisfy the guideline values;
4. private well owners should be advised to avoid drinking soft water for a long term by using softeners appropriately (i.e. for non-consumptive uses only) for example by installing a water pipe to bypass the kitchen tap water;
5. private well owners should be advised how to access local public health officers to discuss well water quality, testing schedule, testing results, treatment methods, well maintenance and health concerns since they manage the well water quality by themselves;
6. public awareness of improving the well water quality should be enhanced; and
7. various technical supports for private well owners should be provided by the experts in the fields of agricultural field engineering, public health inspection, and groundwater hydrochemistry.

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List of Abbreviations and Glossary

Routine Testing

$CaCO_3$	Calcium carbonate
EC	Electrical Conductivity
TDS	Total Dissolved Solid
Ca	Calcium
Mg	Magnesium
K	Potassium
HCO_3	Bicarbonate
CO_3	Carbonate
Cl	Chloride
Na	Sodium
SO_4	Sulfate
Fe	Iron
F	Fluoride
NO_3	Nitrate
NO_2	Nitrite

Trace Element Testing

Al	Aluminum
Sb	Antimony
As	Arsenic
Ba	Barium
B	Boron
Cd	Cadmium
Cr	Chromium
Co	Cobalt
Cu	Copper
Pb	Lead
Mn	Manganese
Hg	Mercury
Mo	Molybdenum
Ni	Nickel
Se	Selenium
Ag	Silver
Tl	Thallium
Ti	Titanium
U	Uranium
V	Vanadium
Zn	Zinc

Others

AHW	Alberta Health and Wellness
BRB	Beaver River Basin
BRWA	Beaver River Watershed Alliance
GIS	Geographic information systems
GPS	Global Positioning System
HC	Health Canada
HPLC	High Performance Liquid Chromatograph
IC	Ion Chromatograph

ICPMS	Inductively Coupled Plasma Mass Spectrometer
LOQ	Limit of Quantitation
ORS	Octopole reaction system
PEEK	Polyetheretherketone
PET	Polyethylene terephthalate
PP	Polypropylene
QC	Quality control
SPSS	Statistical Package for the Social Sciences

1. INTRODUCTION

Under the framework of the *Alberta Water for Life Strategy* to ensure safe drinking water for all Albertans, Alberta Health initiated a domestic well water quality monitoring and human health assessment program in Alberta in 2009. This program will be conducted in selected regions in Alberta as needed. The components of the program include:

1. characterizing the domestic well water quality at a provincial level or selected regions of the province based on physical and chemicals testing;
2. testing routine physical properties, chemical parameter, trace elements, pesticides, and/or bacteria in domestic well water in the selected regions of Alberta; and
3. assessing human exposure to selected chemicals in drinking water related to human health risk.

The first project entitled "Domestic Well Water Quality – Characterization, Physical and Chemical Testing 2002 and 2008" was completed in 2010. The average levels of chemicals and spatial patterns in domestic well water across Alberta were reported based on 2002-2008 data. The information generated in this project provided the basis for identifying the regions and potential public health issues for monitoring and human exposure assessment activities.

The current project focuses on the Beaver River Basin (BRB) region. The BRB region is selected because there were two surveys of well water quality were conducted by Alberta government departments ten years ago, public concerns about potential health risks resulting from exposure to arsenic and uranium, and revision of Canadian Drinking Water Quality guideline for arsenic from a level of 0.025 mg/L to 0.1 mg/L in 2006.

In 1999 – 2000, Alberta Health conducted a 13-month survey of arsenic levels in domestic well water in the BRB region, and other selected regions in Northern Alberta (AHW 2000). Fifty nine well owners participated in this survey in the BRB region. The survey result showed that 22 per cent of annual average arsenic levels in the raw water samples were in excess of 0.025 mg/L (Canadian Drinking Water Guideline for Arsenic as of 1998). In 2000, Alberta Environment and Sustainable Resource Development conducted a hydrogeologic survey to explore the possible natural causes for occurrence of arsenic in groundwater in the Beaver River Basin area (AENV 2000). The survey results showed that the high arsenic levels in groundwater were most likely related to low redox conditions[1] and associated with the levels of dissolved iron, and the high arsenic levels in shallow wells are of local origin and not from underlying aquifers.

[1] Redox refers to oxidation – reduction reactions which entail the transfer of electrons from or to a reactant in making the product. For example, elemental sulfur can be oxidized to sulfate or reduced to sulfide. In groundwater that is well oxygenated, oxidized species (i.e. sulfates, nitrates, ferric iron +3 oxidation state, arsenic +5 oxidation state) will prevail,

Alberta Health is conducting this follow-up survey in order to provide more detailed information on domestic well water quality for well owners and assist them in making decisions as to how to improve their drinking well water quality. The objectives of this survey include to:

1. assessing long-term suitability of domestic well water quality for well owners by monitoring physical properties and chemical concentrations in raw and treated domestic well water samples and comparing the chemical levels to both aesthetic quality-based and health-based guidelines;
2. assessing exposure to chemicals relevant to human health in domestic well water by collecting information on drinking water consumption patterns and calculating daily chemical intake;
3. assessing human health risk from exposure to arsenic in drinking water by comparing exposure intake and health effect information in the literatures;
4. assisting well owners to improve well water quality by providing them with the information about well maintenance and water treatment strategies to domestic well owners; and
5. building information and better understanding of domestic well water quality in specific regions of the province.

In this report, the results are discussed based on:

1. levels of physical properties and chemicals in the raw and treated water samples;
2. changes in chemical levels before and after water treatment in relation to treatment methods used;
3. amount and patterns of water consumption;
4. well maintenance related to drinking water for humans; and
5. estimated exposure levels of selected chemicals through drinking water consumption.

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but if dissolved oxygen is depleted, then reduced species may prevail (i.e. sulfides, nitrite or ammonia, ferrous iron +2 oxidation state, arsenic +3 oxidation state).

2. METHODS AND MATERIALS

2.1 Questionnaires

Criteria for Well Selection

The criteria for selection of the domestic wells were that

1. wells are located in the Beaver River watershed;
2. wells are used as drinking water for humans;
3. wells were tested for trace elements in the 1999-2000 AHW survey if applicable; and
4. wells were never tested for trace elements previously.

Recruitment

Potential participants were identified as :

1. participants from the 2000 AHW survey were re-contacted by phone;
2. private well owners who had called the public health officers previously with concerns about their well water; and
3. a technician asked for referrals from other well owners, from the Beaver River Watershed Alliance and their members from the local public health inspectors and municipal officials.

The technician conducted an initial telephone interview (Appendix A) to potential, eligible participants to explain the purposes of the survey, and identify whether or not the well owners were willing to participate in the survey. Appointments for home visit were made after the owners agreed to participate in the survey.

Site-Visit Questionnaire

During the home visit, the information letter and consent form were reviewed and signed by the participant and technician (Appendix A). The in-person interview was conducted (Appendix A) in order to collect the following information:

1. previous water testing results if available;
2. well identification number, well depth, well maintenance and protection;
3. well water treatment methods;
4. sources of water used for human drinking (e.g. tap water or bottled water; and
5. amount and patterns of water consumption.

2.2 Field Collection

The water samples were collected after the interview. The standard sampling protocol is described in Appendix B.

Six well water samples per household or eleven well water samples per household were collected depending on the well water treatment status. If owners use raw well water as drinking water, five kitchen tap water samples per household were collected plus one stabilized sample from the well head. If owners treated their well water for drinking, five kitchen tap water samples (treated well water) and five raw well water samples taken from the well head per household were collected plus one stabilized sample from the well head.

<u>Sample collection for Routine and Trace Element Analysis</u>

All collection supplies: requisition forms, sample labels, 500-mL polyethylene terephthalate (PET) bottles, tri-wall plain ziplock bags and ampoules of 5-mL 70% nitric acid with plastic ampoule breakers were provided by the Alberta Centre for Toxicology for all sample collections. All lots of collections bottles were verified to be free of contamination for routine analyses and trace elements.

Raw water samples were collected from the *kitchen tap* if the water was *not treated*. Raw water samples were collected from the *hosebibs* prior to treatment or *well head* if the water was *treated*. After purging for 5 minutes, each sample was collected in a 500-ml PET bottle. The first sample was collected without adding nitric acid for routine chemical analysis. The second sample was immediately preserved with 5 mL nitric acid for trace element analysis. The bottles were tightly capped and inverted several times to completely mix the sample. The technician filled out a standard requisition form. The bottle was properly labeled for routine chemical analysis and trace metal analysis with a unique sample identification number.

<u>Sample Collection for Arsenic Species</u>

A third set of samples, raw and treated samples, were taken to assess the species of As in the water. Acetic acid and EDTA were used as preservatives and were added to the sampling bottles to reach final concentrations of 87 mM acetic acid and 1.34 mM EDTA. Two 250-mL polypropylene (PP) bottles, each containing 10.8 mL of 2.0 M acetic acid and 3.35 mL of 0.1 M EDTA solutions, were supplied to each sampling site. All treated water samples were taken from the kitchen tap. Water samples were also collected from kitchen tap if the water was not treated. If the water was treated, raw water samples were collected from the hosebibs or well head. After purging for 5 minutes, each sample was collected in 250-mL PP bottles.

Sample Transportation

All the samples were kept at 4 °C in the refrigerator prior to shipping. Routine and trace element samples were packed in the cooler and shipped through the Bonnyville office to the Alberta Centre for Toxicology in Calgary via over night courier. Arsenic species samples were packed in the cooler and shipped through the Provincial laboratory of Public Health to Analytical and Environmental Toxicology Division at the University of Alberta in Edmonton.

2.3 Laboratory Analysis

The detailed laboratory analysis methods for physical-chemical testing and trace element testing are described in Appendix B. The limit of quantitation (LOQ) is defined as the concentration of the lowest calibrator from the linearity study.

Routine Physical and Chemical Analysis

pH was determined by a pH probe, and a set of calibrators and QCs were run before and after each batch.

Alkalinity was determined using an auto titration system (PC-Titrate, Man-Tech Associates Inc) in conjunction with a conductivity electrode and pH electrode. (USEPA method 310.1 - the Titrimetric method). A set of calibrators and QCs were run before and after each batch. Results were expressed as (mg/L) $CaCO_3$ which is a convention used for convenience of reporting but which otherwise has no chemical meaning or interpretation.

Total hardness was determined from the concentrations of calcium and magnesium as determined by ICP-MS. Results were expressed as an equivalent concentration of $CaCO_3$ which is a convention used for convenience of reporting but which otherwise has no chemical meaning or interpretation.

Carbonate (CO_3) and bicarbonate (HCO_3) were calculated by the pH titration results and were transformed automatically to alkalinity.

Electrical conductivity (EC) was determined using the auto titration system (PC-Titrate, Man-Tech Associates Inc) in conjunction with a conductivity electrode and pH electrode. A set of calibrators and QCs was run before and after each batch.

The determination of total dissolved solids (TDS) was performed by ICPMS, PC-Titrate and IC, and calculated from the concentrations of the cations (positively charged) and anions (negatively charged) in the water sample. This calculation procedure is commonly used for freshwater where TDS is relatively low, but the absolute measure of TDS is based on filtering a water sample to remove any suspended matter, followed by evaporation of the water and measurement of the resulting dried residue.

Nitrate is the most completely oxidized form of nitrogen. Nitrate/nitrite concentrations were determined using the Metrohm 761 Ion Chromatograph (IC) in conjunction with a chemical suppressor and conductivity detector. The results in this report are expressed as the mg of nitrogen present in either nitrate or nitrate

<u>Trace Element Analysis</u>

Analysis for twenty one trace elements was performed on the Agilent 7500c Inductively Coupled Plasma Mass Spectrometer (ICP-MS) with Octopole Reaction System (ORS). The sample was delivered by peristaltic pump directly into the ICP-MS through a MicroFlow PFA-100 nebulizer. The sample aerosol was then ionized by the Argon plasma source. When the ions entered the ORS, they interacted with the reaction gas (either hydrogen or helium), resulting in a reduction of any molecular interference. The ions were focused into a quadrupole mass analyzer and separated based on their mass/charge ratio.

<u>Method for Arsenic Species Analysis</u>

Arsenic species analysis in water was performed by using HPLC-ICP MS (Le et al. 1998; Gong et al. 2006).

Arsenic species in water samples were quantified using high performance liquid chromatography (HPLC) separation with inductively coupled plasma mass spectrometry (ICPMS) detection. An Agilent 1100 series HPLC system was coupled with Agilent 7500cs octopole ICPMS system (Agilent Technologies, Japan). The ICP was operated at a radio frequency power of 1550 W, and the argon carrier gas flow rate was 0.9-1.0 L/min. The ICPMS was operated with helium mode, and the introduction of helium (3.5 mL/min) to the octopole reaction cell was to reduce isobaric and polyatomic interferences. Arsenic was monitored at m/z 75.

Chromatographic separation of inorganic arsenite (AsIII) and arsenate (AsV) was achieved on a reversed-phase ODS-3 column (Phenomenex, 30×4.6 mm, 3-µm particle size) with an ODS guard cartridge (4×3 mm). The column was placed inside a column temperature compartment, which was maintained at 50 °C. The aqueous mobile phase contained 5 mM tetrabutylammonium hydroxide, 5% methanol and 3 mM malonic acid (pH 5.65), and its flow rate was 1.2 mL/min. An aliquot of 50 µL water samples was injected for analysis. The effluent from the HPLC column was directly introduced into the nebulizer of the ICPMS system using a polyetheretherketone (PEEK) tubing. Chromatograms from HPLC separation and ICPMS detection were recorded and processed using the ChemStation software (Agilent Technologies, Santa Clara, CA).

A standard reference material SRM1640 Trace Elements in Natural Water (from National Institute of Standards and Technology, Gaithersburg, MD) was used for quality control. The method detection limits for both AsIII and AsV were 0.0001 mg/L.

2.4 GIS Mapping

The coordinates for every well were stored as GPS coordinates (collected in the field) and legal land descriptions. The coordinates were loaded into a GIS (Manifold GIS v8) along with the legal land description boundaries to check for discrepancies between the two data sources. No major discrepancies were found in the GPS coordinates vs legal land descriptions. The coordinates of the centre of the quarter section were used in those instances where these coordinates were not collected with a GPS.

All maps were created using Canvas+GIS v11. The location of each well is shown in the approximate location since some were moved slightly to remain visible in the final maps.

Two sets of maps were produced, one set for raw (untreated) water and the second set for treated water. Comparisons of the raw and treated water map for a particular test provide a visual illustration of the effects of water treatment for the parameter selected. The classification scheme was consistent for each parameter for both raw and treated water.

Some of the parameters tested have corresponding Canadian Drinking Water Guidelines values that provide context of values that should not be exceeded for personal water consumption. Maps of parameters with corresponding guidelines are shown using a maximum of four categories: green colours highlight wells with results below guidelines and orange/red highlight wells with results above guidelines for a particular parameter. Dark green was used to show values well below guidelines, light green those just below guidelines, orange those just above guidelines, and red well above guidelines. The values used for creating these categories appear in the corresponding legends of the maps. Some maps show fewer categories because of data distribution characteristics.

For the parameters without the guideline values, the mapping technique was based on the characteristics of the data. Three different scenarios were encountered:

1. If all values were less than detected limits, all sites were shown using a single colour indicating that all sites were below detected limits;
2. If the median was less than detected limits but not all values were less than detected limits, the maps showed sites below and above detection.

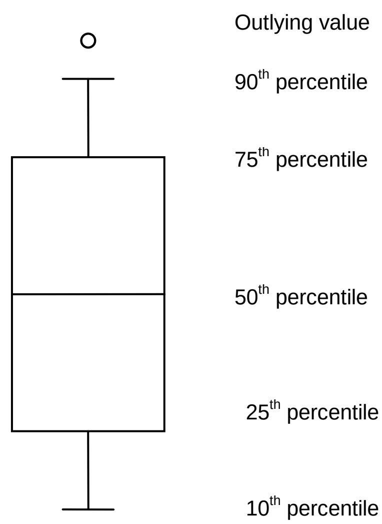
Two colours were used to identify sites below detected limits and values above detected limits; and

3. If the median was greater than detected limits, the mapping categories were the median, and 50% of the median above and below the median. For example, with a median of 0.002, the class breaks were 0.001 (0.002 - 0.001), 0.002 (median), and 0.003 (0.002 + 0.001) -where 0.001 is 50% of the value of the median.

2.5 Statistical Analysis

The statistical analysis was performed by using SPSS (Version17) package. The distribution of each parameter was found to not fit a normal (Gaussian) distribution. The distributions were generally right – skewed (except for pH) meaning that the distribution showed an extended tail for higher values to the right of the median. This characteristic is also evident when the mean substantially exceeds the median. For a normal distribution these two measures would be equal. Right–skewed distributions are commonly found with environmental quality data. The statistical summaries were performed for mean, median, standard deviation, minimum value, maximum value, and the 10^{th}, 25^{th}, 75^{th}, 90^{th} percentile values.

The box plot was used to demonstrate the changes of chemical levels before and after treatment. A box plot is a summary plot that plots graph data as a box representing statistical values. The boundary of the box closest to zero indicates the 25th percentile, a line within the box marks the median (50^{th} percentile), and the boundary of the box farthest from zero indicates the 75th percentile. Whiskers (error bars) above and below the box indicate the 90th and 10th percentiles. The dots outside the box indicate outlying values.



3. RESULTS AND DISCUSSION

3.1 Overview of the Beaver River Basin Region

The Beaver River Basin in Alberta is located in east-central Alberta. It extends eastward through the urban centers of Bonnyville, Cold Lake, and Grand Centre and across Saskatchewan and Manitoba to Hudson's Bay (Figure 1). Municipalities including Bonnyville, St Paul County, Lakeland county and Smoky Lake county are within the Beaver River Basin watershed (Figure 2).

The total population is 39,475 based on the survey of 2006 Canadian Census data (Statistic Canada 2010). Population counts include the city of Cold Lake (11,991), Bonnyville (5,832), other towns, Reserves, summer villages, and Métis Settlements. The rural population is 14,785 excluding the population of Métis Settlements, Reserves, towns, villages and portions of the counties that are outside the river basin boundary.

Based on the well drilling reports provided by Alberta Environment, there are over 12,000 wells drilling records in the BRB region collected since 1914 (personal communication). The number of wells used for domestic drinking water use is likely less than one third of the total wells. It is very difficult to determine how many wells have been abandoned or are now used solely for non-domestic purposes.

3.2 Sample Summary

The population distribution and sampling sites are showed in Figure 3. The majority well sites were located in the area with a high density of rural population. The sampling sites by underlying bedrock geological formations are shown in Figure 4. Most of the sample sites were located in the Lea Park Formation (marine formation). There were two sample sites located in the LaBiche Formation (marine formation), five inside the Belly River Formation (non marine) and three in the border between Lea Park and Belly Formations. The characteristics of bedrock formation are shown in Appendix C.

A total of 152 domestic well sites were selected. The wells were drilled between 1971 and 2008. An average well depth was approximately 37.5 m. 66 per cent of wells were tested for chemicals before this survey. Among these wells, 32 well owners used raw water for house use and 120 well owners used treated water. 146 raw water samples were collected. Out of 146, 32 raw water samples were collected from the kitchen taps and 114 raw water samples were collected from well heads. 120 treated water samples were collected from the kitchen taps. Among 120 treated water well sites, six raw water samples were not collected from well heads. This means that a total 114 paired pre- and post- water samples were collected for comparison analysis (before and after water treatment).

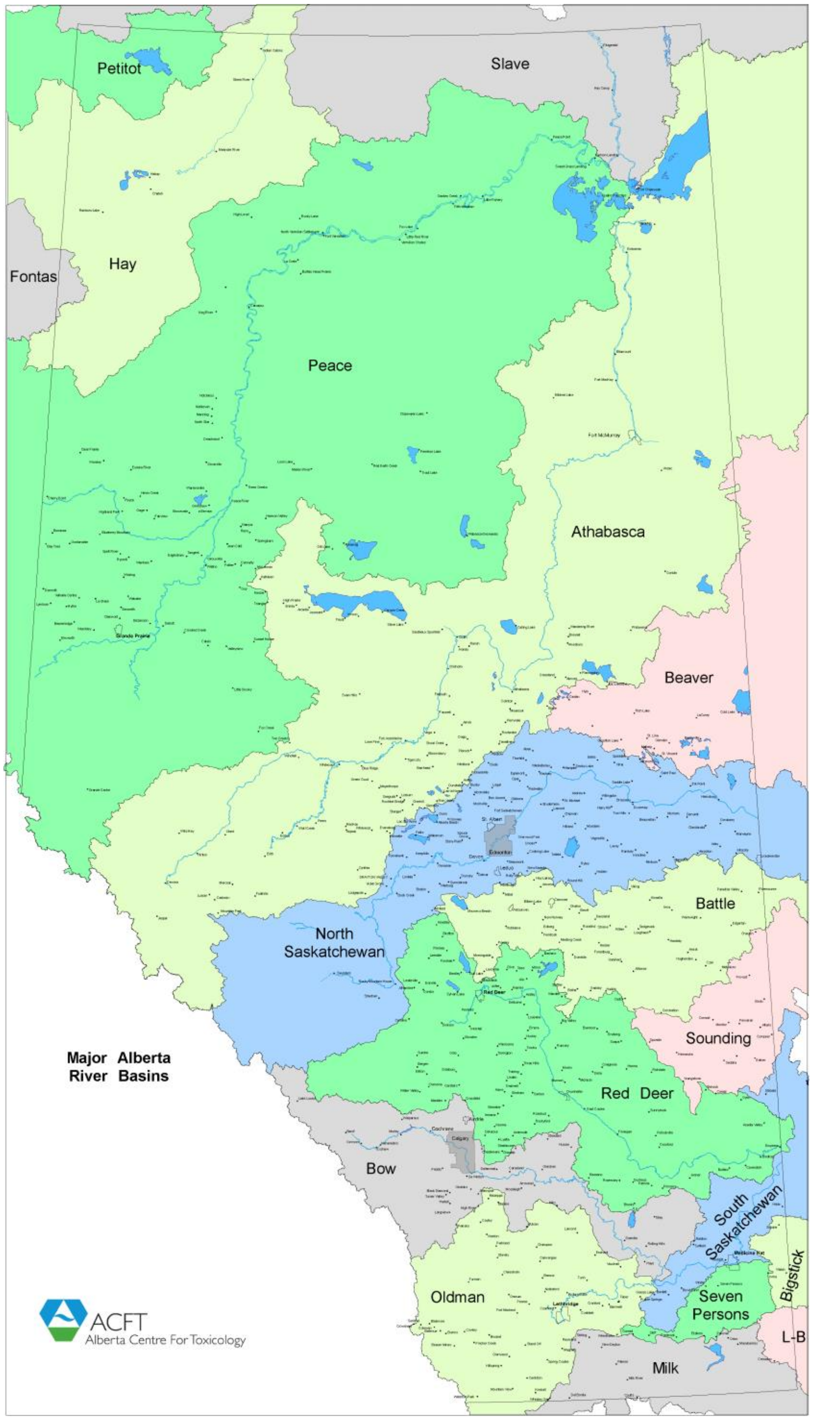


Figure 1 Location of the Beaver River Basin

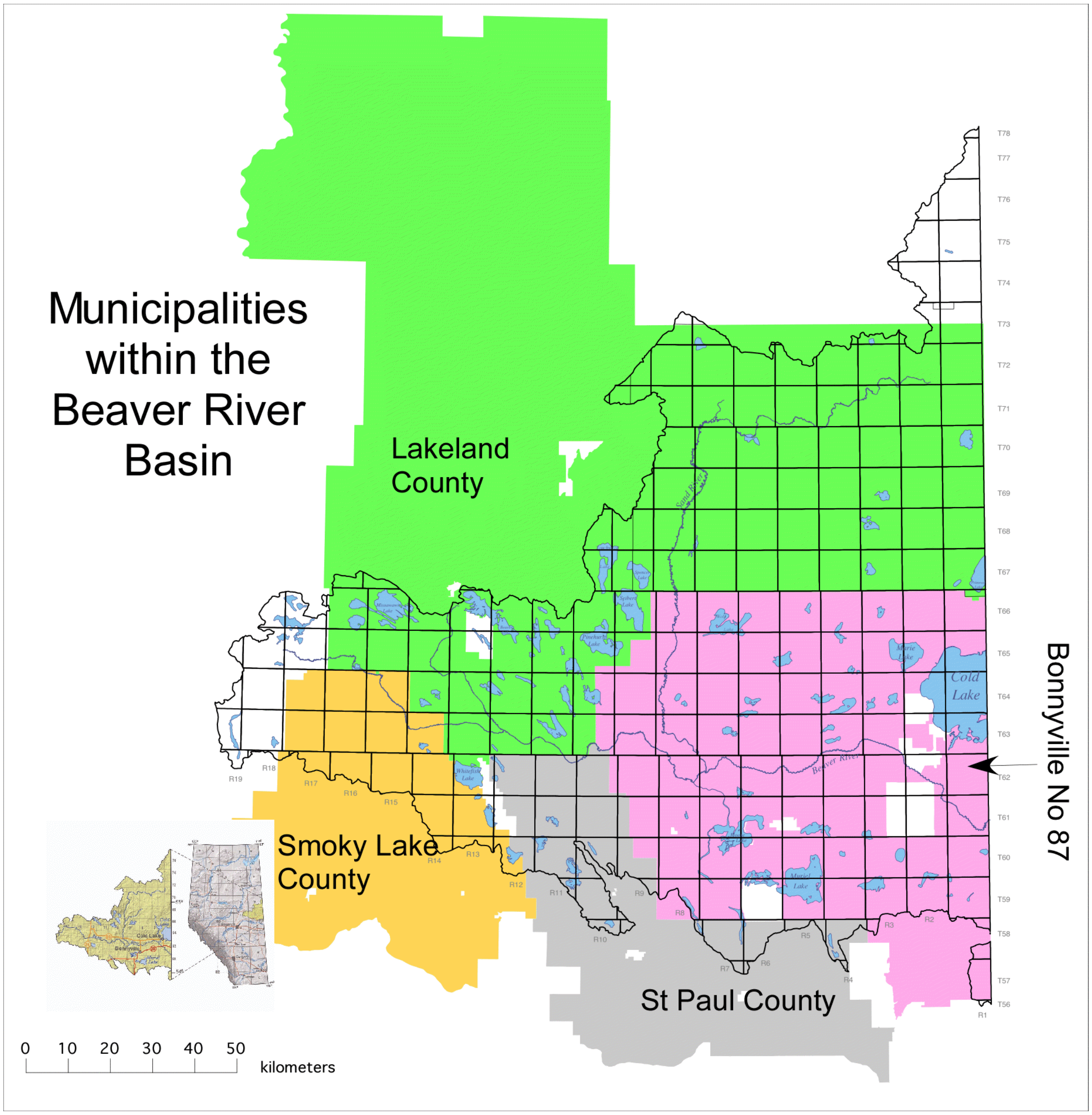


Figure 2 Municipalities within the Beaver River Basin

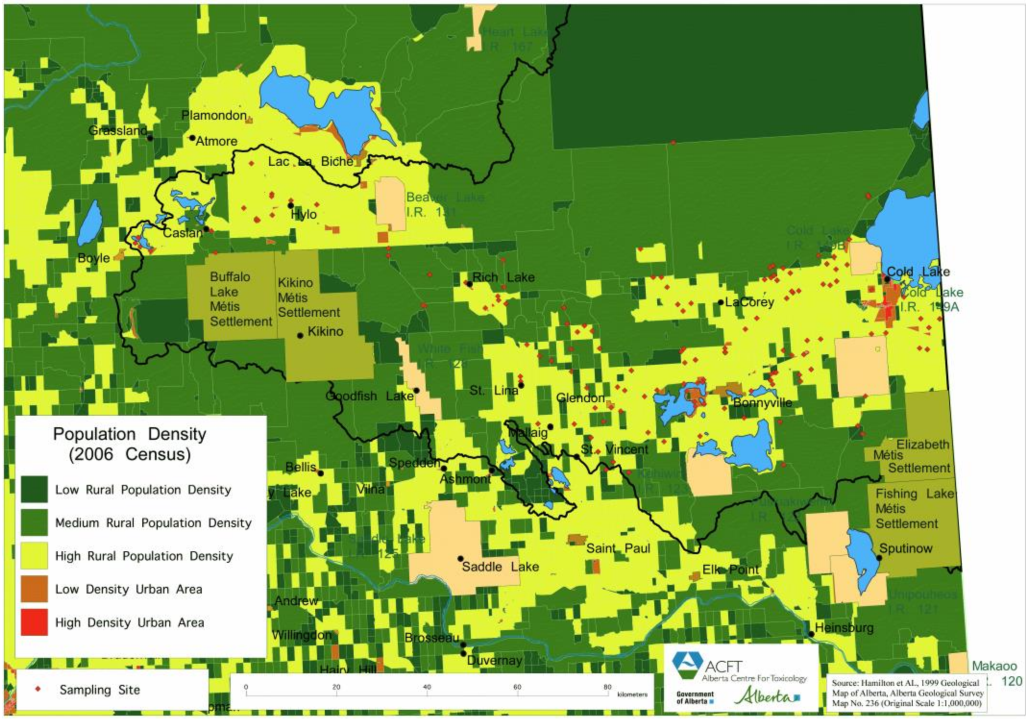


Figure 3 Population Distribution and Sampling Sites

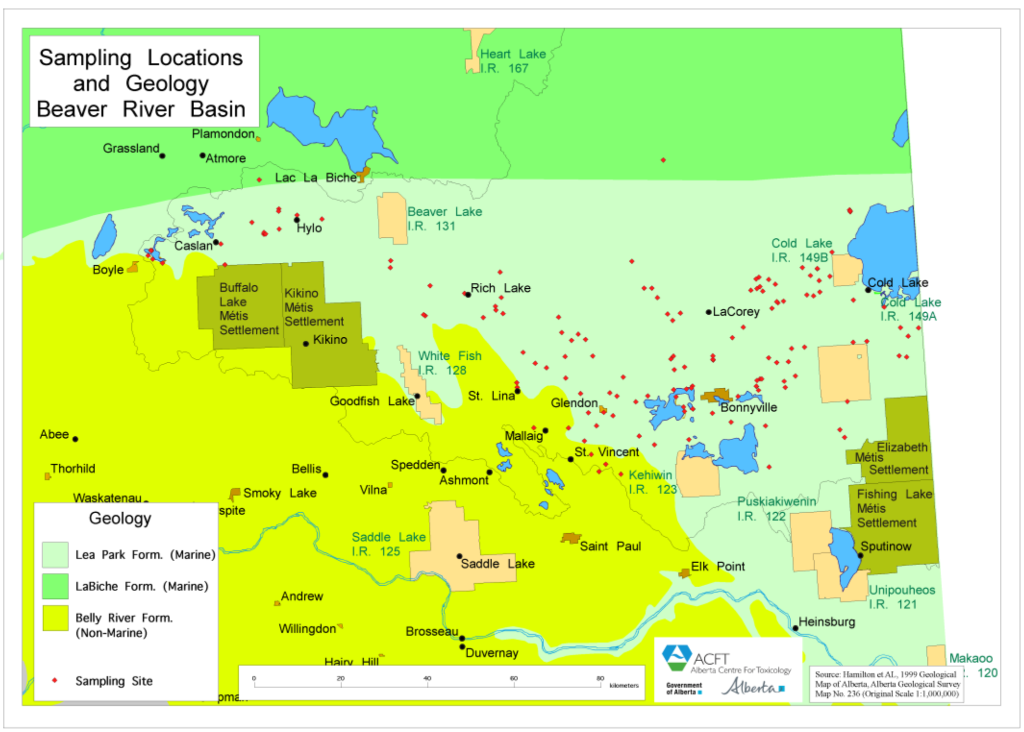


Figure 4 Sampled Well Sites by Underlying Bedrock Geological Formation

Types of treatment methods in 120 houses are showed below:

Treatment Method	Number of House	% of Total House
Softener	109*	91
Iron filter	45	38
Carbon filter	12	10
Reverse osmosis	11	9.2
Distiller	8	6.7
Chlorinator	3	2.5
1 treatment methods	66	55
2 treatment methods	43	36
3 treatment methods	10	8
5 treatment methods	3	2.5
5 treatment methods	1	0.8

* The paired water samples (before and after treatment) were collected in 103 houses.

The summary information of raw and treated water samples are listed in Table 1 and 2 for routine testing and Table 3 and 4 for trace element testing. The reported detection levels are described as “Limits of Quantitation” (LOQ). The LOQ means the lowest levels of physical parameters and chemicals that can be measured using the specified laboratory instruments and analysis methods. The units are mg/L (milligram per liter) for all parameters except for conductivity expressed as μS/cm at 25 °C and pH which has no units. The ion balances were within ± five per cent.

Alkalinity, pH, conductivity, TDS, bicarbonate, hardness, calcium, magnesium, sodium, potassium, chloride and fluoride were detected in all raw samples as would be expected. Alkalinity, pH, conductivity, TDS, bicarbonate, and hardness were detected in all the treated samples. Percentages of detected samples for calcium, magnesium, sodium, potassium, chloride, iron, fluoride, nitrate-N and nitrite-N decreased in the treated water samples compared to the raw water samples.

Aluminum, barium, boron, manganese, molybdenum, titanium and zinc were detected in over 80 per cent of the raw water samples. Boron, titanium and zinc were detected in over 80 per cent of the treated water samples. Beryllium, cadmium, chromium, mercury, and thallium were not detected in all the raw and treated water samples.

Table 1 Summary of Raw Water Sample Information for Routine Testing

	Sample Size	% of Reported Detection	Reported Detection Level	Unit
pH	146	100	-3 to 14	no unit
Alkalinity (as $CaCO_3$)	146	100	0.3	mg/L
Electrical Conductivity	146	100	1.87	µS/cm
Total Dissolved Solid	146	100	5.11	mg/L
Hardness (as $CaCO_3$)	146	100	0.66	mg/L
Calcium (as Ca)	146	100	0.1	mg/L
Magnesium (as Mg)	146	100	0.1	mg/L
Potassium	146	100	0.1	mg/L
Bicarbonate (as $CaCO_3$)	146	100	0*	mg/L
Carbonate (as $CaCO_3$)	146	9.0	0*	mg/L
Chloride	146	100	1.0	mg/L
Sodium	146	100	1.0	mg/L
Sulfate	146	97	1.0	mg/L
Iron	146	89.7	0.01	mg/L
Fluoride	146	100	0.1	mg/L
Nitrate (as N)	146	45.5	1.0	mg/L
Nitrite-N (as N)	146	22.8	0.1	mg/L

* value based on the detection limit for total alkalinity of 1ppm.

Table 2 Summary of Treated Water Sample Information for Routine Testing

	Sample Size	% of Reported Detection	Reported Detection Level	Unit
pH	120	100	-3 to 14	no unit
Alkalinity (as $CaCO_3$)	120	100	0.3	mg/L
Electrical Conductivity	120	100	1.87	µS/cm
Total Dissolved Solid	120	100	5.11	mg/L
Hardness (as $CaCO_3$)	120	100	0.66	mg/L
Calcium (as Ca)	120	91.7	0.1	mg/L
Magnesium (as Mg)	120	87.6	0.1	mg/L
Potassium	120	94	0.1	mg/L
Bicarbonate (as $CaCO_3$)	120	100	0*	mg/L
Carbonate (as $CaCO_3$)	120	33	0*	mg/L
Chloride	120	96.7	1.0	mg/L
Sodium	120	97.5	1.0	mg/L
Sulfate	120	91.7	1.0	mg/L
Iron	120	69.4	0.01	mg/L
Fluoride	120	87.6	0.1	mg/L
Nitrate (as N)	120	38.8	1.0	mg/L
Nitrite-N (as N)	120	3.3	0.1	mg/L

* value based on the detection limit for total alkalinity of 1ppm.

Table 3 Summary of Raw Water Sample Information for Trace Element Testing

	Sample Size	% of Samples Reporting Detection	Reported Detection Level	Unit
Aluminum	146	100	0.001	mg/L
Antimony	146	8.9	0.001	mg/L
Arsenic	146	74.7	0.001	mg/L
Barium	146	98.9	0.001	mg/L
Beryllium	146	0	0.001	mg/L
Boron	146	100	0.01	mg/L
Cadmium	146	0	0.001	mg/L
Chromium	146	0	0.001	mg/L
Cobalt	146	13.7	0.001	mg/L
Copper	146	72.6	0.001	mg/L
Lead	146	17.1	0.001	mg/L
Manganese	146	99.3	0.001	mg/L
Mercury	146	0	0.001	mg/L
Molybdenum	146	81.5	0.001	mg/L
Nickel	146	38.4	0.001	mg/L
Selenium	146	11.6	0.001	mg/L
Silver	146	0	0.001	mg/L
Thallium	146	0	0.001	mg/L
Titanium	146	99.3	0.001	mg/L
Uranium	146	58.9	0.001	mg/L
Vanadium	146	0.	0.001	mg/L
Zinc	146	100	0.0001	mg/L

Table 4 Summary of Raw Water Sample Information for Routine Testing

	Sample Size	% of Samples Reporting Detection	Reported Detection Level	Unit
Aluminum	120	99.2	0.001	mg/L
Antimony	120	11.7	0.001	mg/L
Arsenic	120	58.3	0.001	mg/L
Barium	120	54.2	0.001	mg/L
Beryllium	120	0	0.001	mg/L
Boron	120	100	0.01	mg/L
Cadmium	120	0	0.001	mg/L
Chromium	120	0	0.001	mg/L
Cobalt	120	2.5	0.001	mg/L
Copper	120	79.2	0.001	mg/L
Lead	120	10.8	0.001	mg/L
Manganese	120	73.3	0.001	mg/L
Mercury	120	0	0.001	mg/L
Molybdenum	120	69.2	0.001	mg/L
Nickel	120	20	0.001	mg/L
Selenium	120	5.8	0.001	mg/L
Silver	120	1.7	0.001	mg/L
Thallium	120	0	0.001	mg/L
Titanium	120	80.8	0.001	mg/L
Uranium	146	50	0.001	mg/L
Vanadium	120	0	0.001	mg/L
Zinc	120	89.2	0.0001	mg/L

3.3 Routine Testing

A statistical summary of physical properties and major/minor ions performed in the routine testing for the raw water samples is listed in Table 5. Characteristics for each parameter are discussed in the following sections.

In order to assess the suitability of domestic well water, some cut-off values were recommended by Health Canada (see the relevant documents in the *Guidelines for Canadian Drinking Water Quality*) such as

1. health-based guidelines,
2. aesthetic-quality-based guidelines,
3. optimal levels of fluoride in drinking water for health benefits,
4. classification of water hardness, and
5. taste classification for TDS.

The percentages of the tested raw water samples fitting these cut-off values (under, between or over) are listed in Table 6. The concentrations of tested parameters with significant changes before and after treatment and treatment methods are showed in Appendix D.

Table 5 Statistical Summary of Parameters in routine Testing

Parameter*	Type	Mean	Median	Min	Max	Percentile			
						10	25	75	90
pH	Raw	8.1	8.1	7.7	8.5	7.9	8.0	8.2	8.3
	Treated	8.1	8.2	6.1	9.5	7.5	8.0	8.3	8.5
Alkalinity	Raw	534	542	111	790	352	463	622	688
	Treated	462	522	1.3	800	49	373	613	694
Electrical Conductivity	Raw	1517	1323	242	5500	741	966	1894	2473
	Treated	1482	1354	4.0	6110	131	858	1955	2779
TDS	Raw	929	826	125	2827	405	552	1172	1619
	Treated	893	830	1.3	3025	68	512	1208	1698
Hardness	Raw	536	484	3.8	1710	195	352	690	930
	Treated	88	12	0.02	1002	0.6	1.9	48	365
Calcium	Raw	127	117	0.9	420	47	88	155	215
	Treated	19	2.6	<0.1	161	0.2	0.5	9.7	92
Magnesium	Raw	53	46	0.4	192	18	31	65	97
	Treated	10	1.1	< 0.1	186	<0.1	0.2	4.5	36
Bicarbonate	Raw	650	661	136	964	429	562	759	839
	Treated	556	633	1.6	976	60	455	729	835
Carbonate	Raw	0.7	0	0	21	0	0	0	0
	Treated	3.7	0	0	83	0	0	5.0	13
Chloride	Raw	86	17	0.7	1415	1.4	3.3	75	263
	Treated	69	14	<1.0	1528	0.8	2.0	44	131
Sodium	Raw	136	85	3.6	895	13	28	174	357
	Treated	230	190	<1.0	1088	8.0	27	386	533
Sulfate	Raw	199	109	<1.0	1474	11	34	257	586
	Treated	179	91	<1.0	1387	0.8	22	237	468
Potassium	Raw	5.4	5.0	1.2	18	3.2	4.1	6.2	8.5
	Treated	107	3.5	<0.1	1150	0.2	0.9	60	439
Iron	Raw	2.0	1.0	<0.01	17	<0.01	02	2.8	5.7
	Treated	0.09	0.04	<0.01	1.9	<0.01	<0.01	0.1	0.2
Fluoride	Raw	0.3	0.2	0.1	0.5	0.1	0.2	0.3	0.4
	Treated	0.2	0.2	<0.1	0.6	<0.1	0.2	0.3	0.4
Nitrate-N	Raw	1.5	<1.0	<1.0	31	<1.0	<1.0	<1.0	4.0
	Treated	1.4	<1.0	<1.0	31	<1.0	<1.0	<1.0	3.0
Nitrite-N	Raw	0.1	<0.1	<0.1	2	<0.1	<0.1	<0.1	0.3
	Treated	0.005	<0.1	<0.1	0.3	<0.1	<0.1	<0.1	<0.1

* Unit for each parameter: see Table 1 and 2.

Table 6 Percentages of the Raw Samples Compared to the Defined Cut-off Values

Parameter	Cut-off Value (mg/L)	% Under	% between	% Over	Value Definition
Fluoride	1.5			0	HC -Health
	2.4			0	AENV -Health
	0.8 – 1.0		0		Optimal level
	< 0.8	100			Sub-Optimal level
Nitrate -N	10	96			HC -Health
Nitrite - N	1.0	96			HC -Health
pH	6.5 – 8.5*		100		HC - aesthetic
	8.5 – 9.0		0		Moderate alkaline
	<6.5	0			Acid-Corrosive
	>9.0			0	Alkaline-scaling
Chloride	≤ 250	89.7			HC - aesthetic
Sodium	≤ 200	79.5			HC - aesthetic
Sulfate	≤ 500	89			HC - aesthetic
Total Dissolved Solid **	≤ 500	16.4			HC - aesthetic
	< 300	3.4			Taste - excellent
	300 - 600		28.8		Taste - good
	600 - 900		23.3		Taste - fair
	900 - 1200		19.9		Taste – poor, salty
	>1200			24.7	Taste-unacceptable
Iron	≤ 0.3	28.8			HC - aesthetic
Hardness	≤ 60	0.7			Soft water
	60 – 120		2.1		Medium hard water
	120 – 180		5.5		Hard water
	> 180			91.8	Vary hard water
	80 - 100		0		Optimal level

* no unit; HC -Health = health-based guideline by Health Canada; HC – aesthetic-based guideline by Health Canada; AENV -Health = health-based standard by Alberta Environment; Optimal level = optimal level for dental health.

** Health Canada (1991) **"**The palatability of drinking water has been rated, by panels of tasters, according to TDS level as follows: excellent, less than 300 mg/L; good, between 300 and 600 mg/L; fair, between 600 and 900 mg/L; poor, between 900 and 1200 mg/L; and unacceptable, greater than 1200 mg/L. Rationales are (1) the most important aspect of TDS with respect to drinking water quality is its effect on taste. The palatability of drinking water with a TDS level less than 600 mg/L is generally considered to be good. Drinking water supplies with TDS levels greater than 1200 mg/L are unpalatable to most consumers; (2) concentrations of TDS above 500 mg/L result in excessive scaling in water pipes, water heaters, boilers and household appliances; and (3) an aesthetic objective of ≤500 mg/L should ensure palatability and prevent excessive scaling. However, it should be noted that at low levels TDS contributes to the palatability of drinking water. "

3.3.1 pH and Alkalinity

- ✓ Domestic well water is neutral (6.5-8.5) in all raw well samples
- ✓ pH values did not change significantly before and after water treatment
- ✓ Alkalinity levels were reduced significantly after water treatment in some households, particularly those using reverse osmosis, iron filters, distillers or activated carbon filters.

pH

The mean and median of pH were 8.1 – 8.2 in raw and treated water samples with a range of 7.7 – 8.5 in raw water samples and 6.1 – 9.5 in treated water samples (Table 5). The difference of pH values before and after water treatment was not significant ($p = 0.4$), but lower pH values (< 6.5) and higher pH values (> 8.5) were observed in more treated water samples than in raw water samples (Figure 5 and Figure 6).

The decreased pH values after treatment were observed in the houses using reverse osmosis units, iron filters or distiller to remove significant amount of alkalinity. Lower pH may increase corrosion of plumbing fixtures and cause an unpleasant, often metallic taste. pH itself, within the range found in groundwater does not pose a health risk to humans, but corrosive pH may increase the levels of some metals such as lead in the water and may pose a health risk if allowed to exceed health-based guidelines.

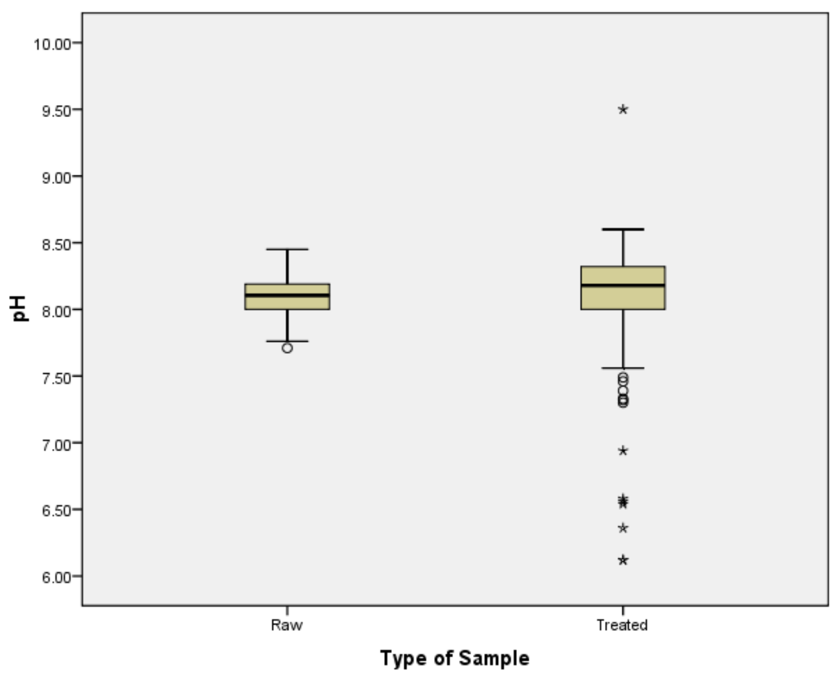


Figure 5 Distribution of pH in Raw and Treated Water Samples

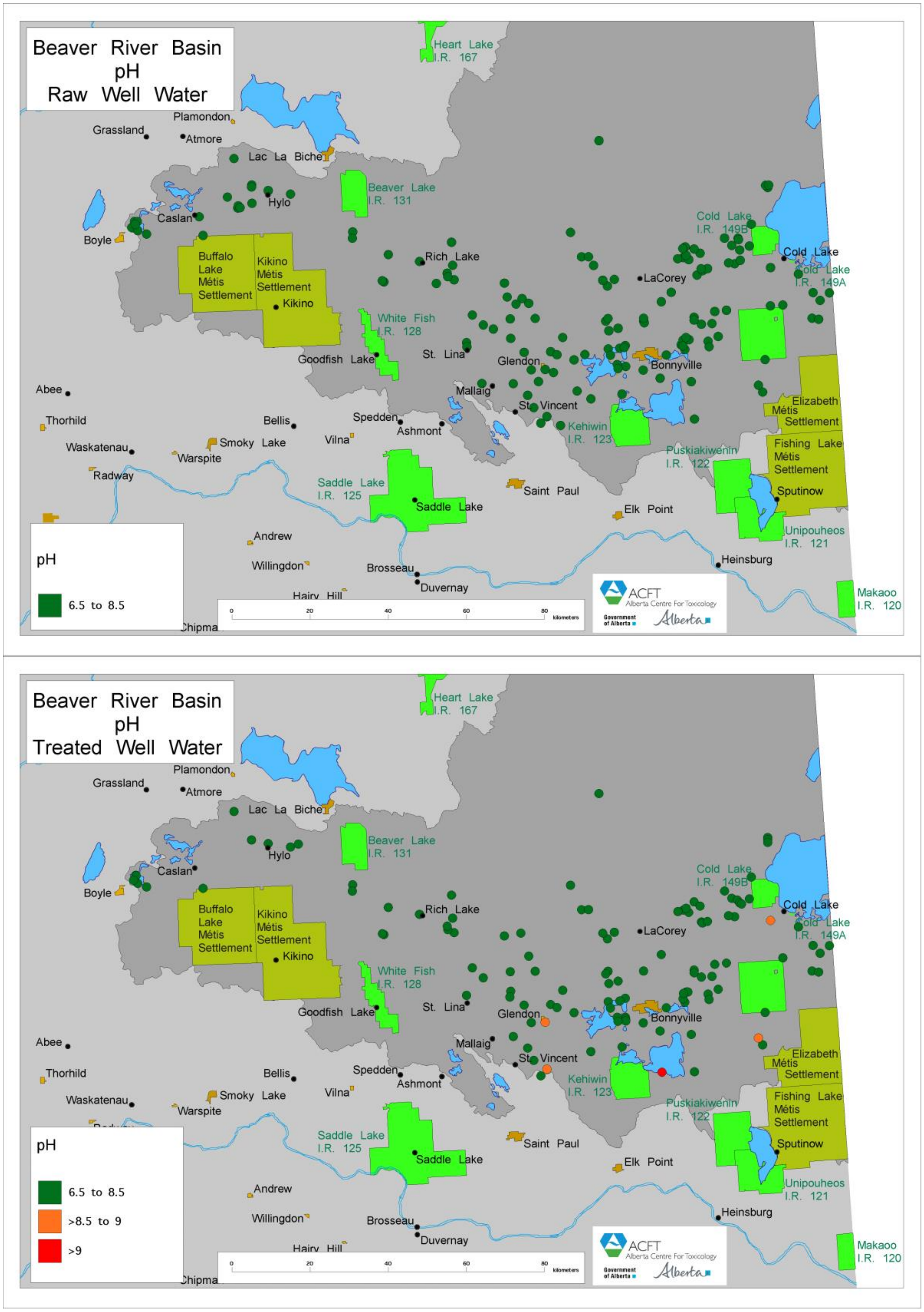


Figure 6 Spatial Patterns with Respect to pH Guideline before and after Treatment

pH value of 9.5 was observed in one household where only one treated water sample was collected and raw water sample was not collected. Very high levels of TDS (2,732 mg/L), sulfate (1,384 mg/L), sodium (470 mg/L) and potassium (607 mg/L) were found in this treated water sample as well. Very alkaline groundwater would likely be associated with the high levels of these chemicals.

The aesthetic quality guideline for pH in Canada is 6.5 – 8.5 (Health Canada 1995). The pH levels were within the guideline values in all raw water samples (Table 6). It reflects that natural groundwater is generally neither acidic nor alkaline in the Beaver River Basin region.

Alkalinity

The mean and median of alkalinity were 534 and 542 mg/L with a range of 111 – 790 m/L in raw water samples, and 462 and 522 mg/L in treated water samples with a range of 1.3 – 800 mg/L, respectively (Table 5). A typical range of alkalinity in groundwater worldwide is 10 to 500 mg/L (Younger 2007).

After treatment, a wider range of alkalinity values in treated water samples was observed than that in raw water samples (Figure 7 and Figure 8).The levels of alkalinity were statistically different before and after treatment ($p < 0.001$). There was considerably reduction (82 to 100 per cent) of the alkalinity levels in the samples collected from 19 households (Table A in Appendix D). Out of 19 households, reverse osmosis units were used in 11 households, iron filters in nine households, activated carbon filters in six households, distillers in seven households and softeners in 18 households. In these households, more combined treatment methods were used. Alkalinity is related to hardness of the water because the major source of alkalinity arises from $CaCO_3$ in carbonate rocks. The significant reduction of alkalinity levels in some samples may be related to hardness level changes due to treatment.

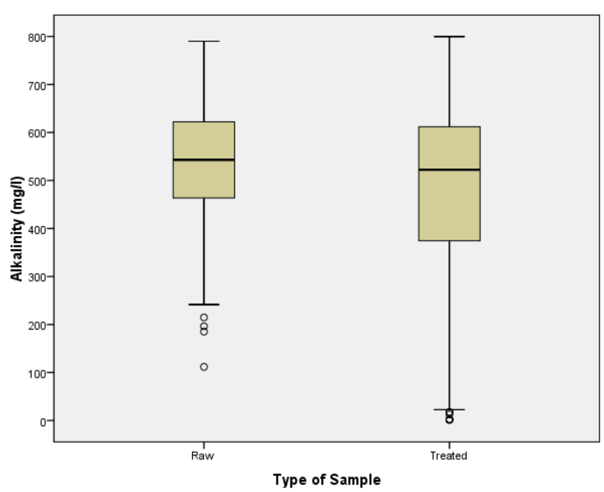


Figure 7 Distribution of Alkalinity in Raw and Treated Water Samples

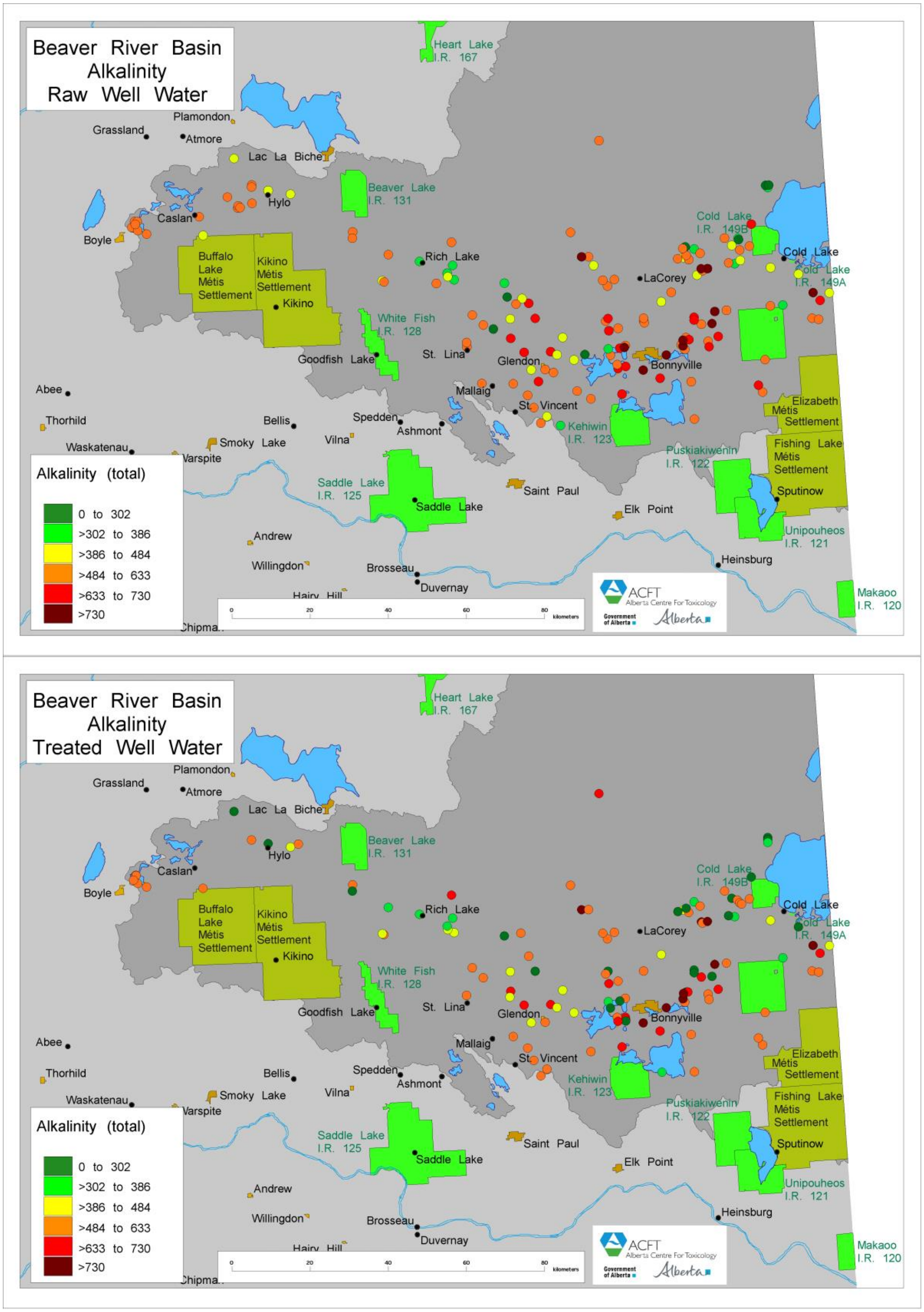


Figure 8 Spatial Patterns of Alkalinity before and after Treatment

3.3.2 Electrical Conductivity and Total Dissolved Solids

- ✓ TDS levels in 16 per cent of raw water samples and 24 per cent of treated water samples were under the Canadian aesthetic quality guideline
- ✓ The overall suitability of domestic well water quality for human drinking based on taste was rated as excellent to fair in 55 per cent raw and treated water samples
- ✓ EC and TDS were reduced significantly after water treatment in 19 households, particularly by using a combination of treatment methods with reverse osmosis units, iron filters, distillers or activated carbon filters

Electrical Conductivity

The mean and median of electrical conductivity (EC) were 1,517 and 1,323 μS/cm at 25°C with a range of 242 – 5,500 μS/cm in raw water samples, and 1,482 and 1,354 μS/cm at 25°C with a range of 4.0 – 6,110 μS/cm in treated water samples, respectively (Table 5). For most natural groundwater, the range of EC varies widely from 15 to 3,000 μS/cm (Younger 2007).

The EC values did not change significantly before and after treatment ($p = 0.7$) in overall samples (Figure 9 and 11). But there was considerably reduction (68 to 100 per cent) of the conductivity levels along with the TDS levels in the samples collected from 19 households ($p < 0.001$).

Total Dissolved Solids

The mean and median of TDS were 929 and 826 mg/L with a range of 125 – 2,827 mg/L in raw water samples, and 893 and 830 mg/L with a range of 1.3 – 3,025 mg/L in treated water samples, respectively (Table 5).

The TDS values did not change significantly before and after treatment ($p = 0.6$) in overall samples (Figure 10 and 12). But the TDS levels changed statistically significant before and after treatment in the samples collected from 19 households ($p < 0.001$). There was a considerable reduction (71 to 100 per cent) of the TDS levels (Table A in Appendix D). Out of 19 households, reverse osmosis units were used in 11 households, iron filter in 9 households, activated carbon filters in 6 households, distillers in 7 households and softeners in 18 households. In these households, more combined treatment methods were used.

TDS is an indicator of the overall suitability of well water for domestic use. TDS causes a salty taste. The Canadian guideline for TDS is 500 mg/L or less to assure the aesthetic quality of drinking water. This guideline value is a blended number based on both taste and corrosion/scaling considerations. In the BRB region, TDS levels were below this guideline occurred in only 16 per cent of raw water samples and 24% in the treated water samples (Table 6).

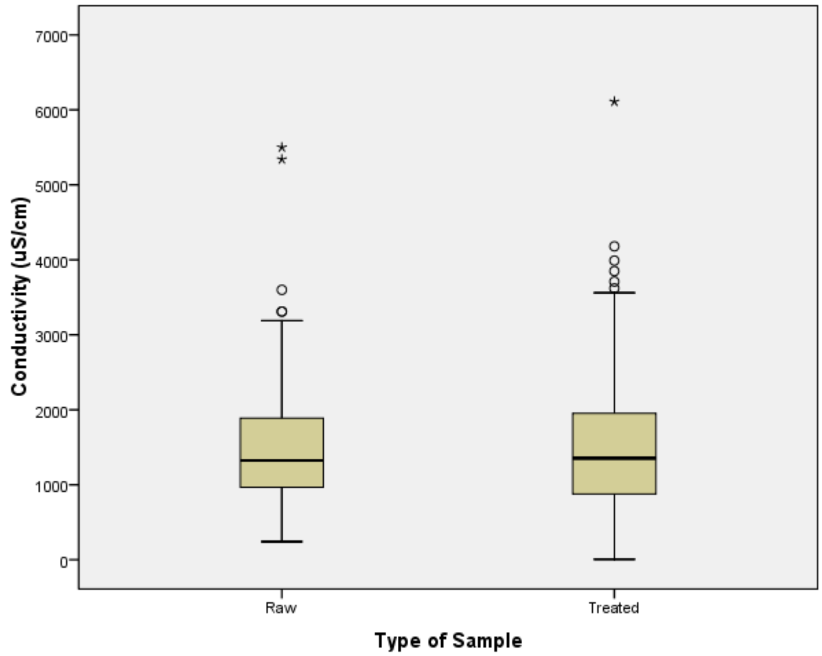


Figure 9 Distribution of EC

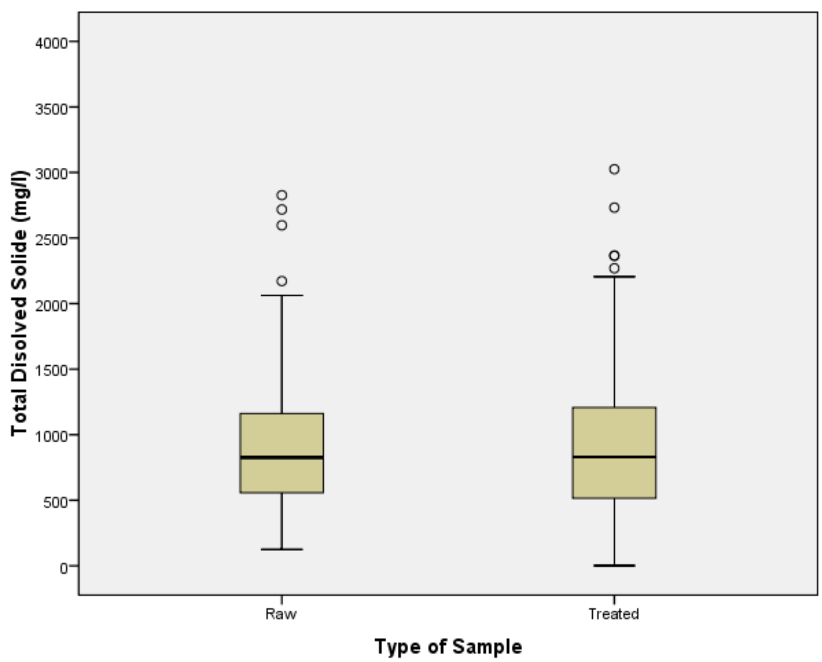


Figure 10 Distribution of TDS

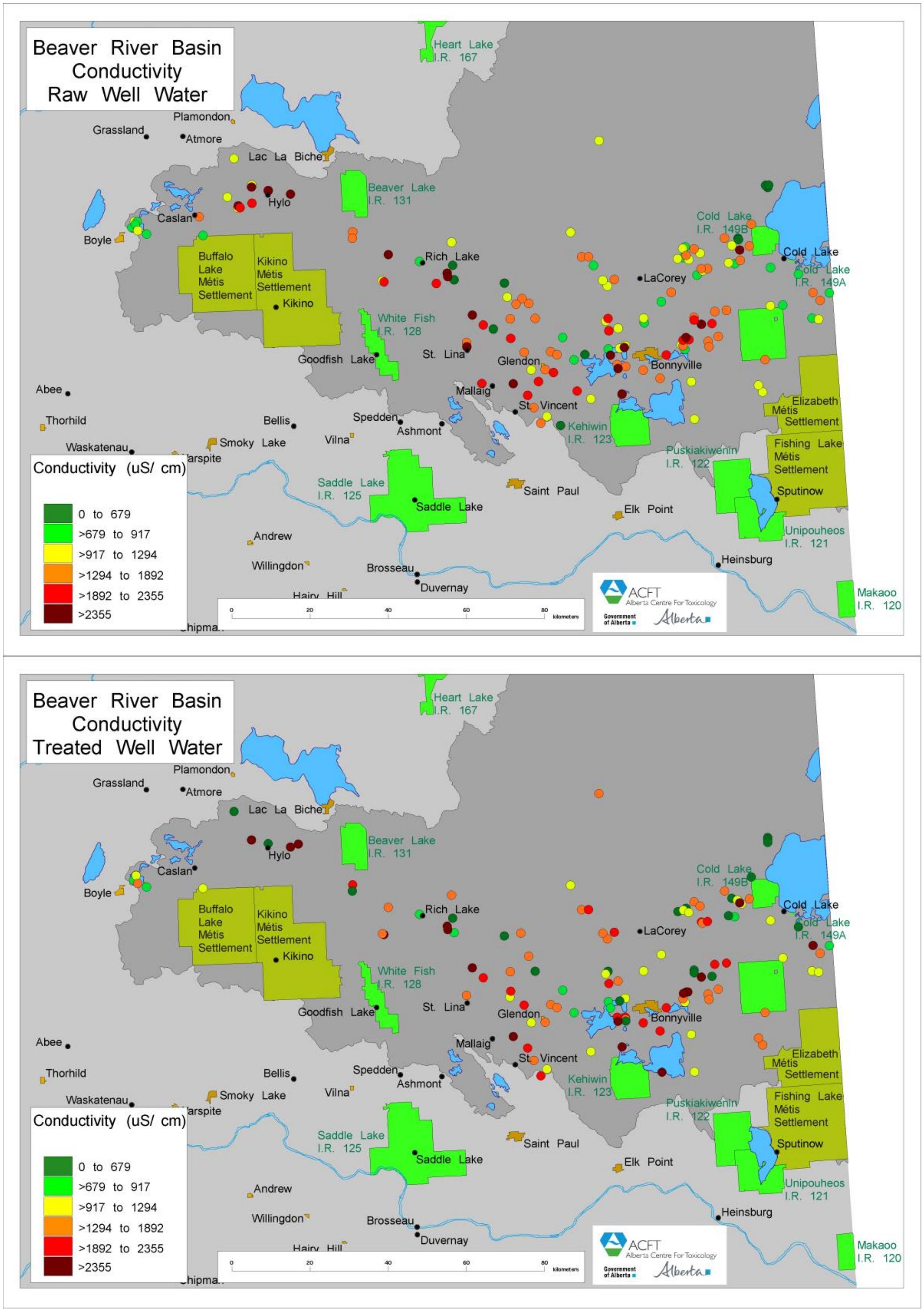
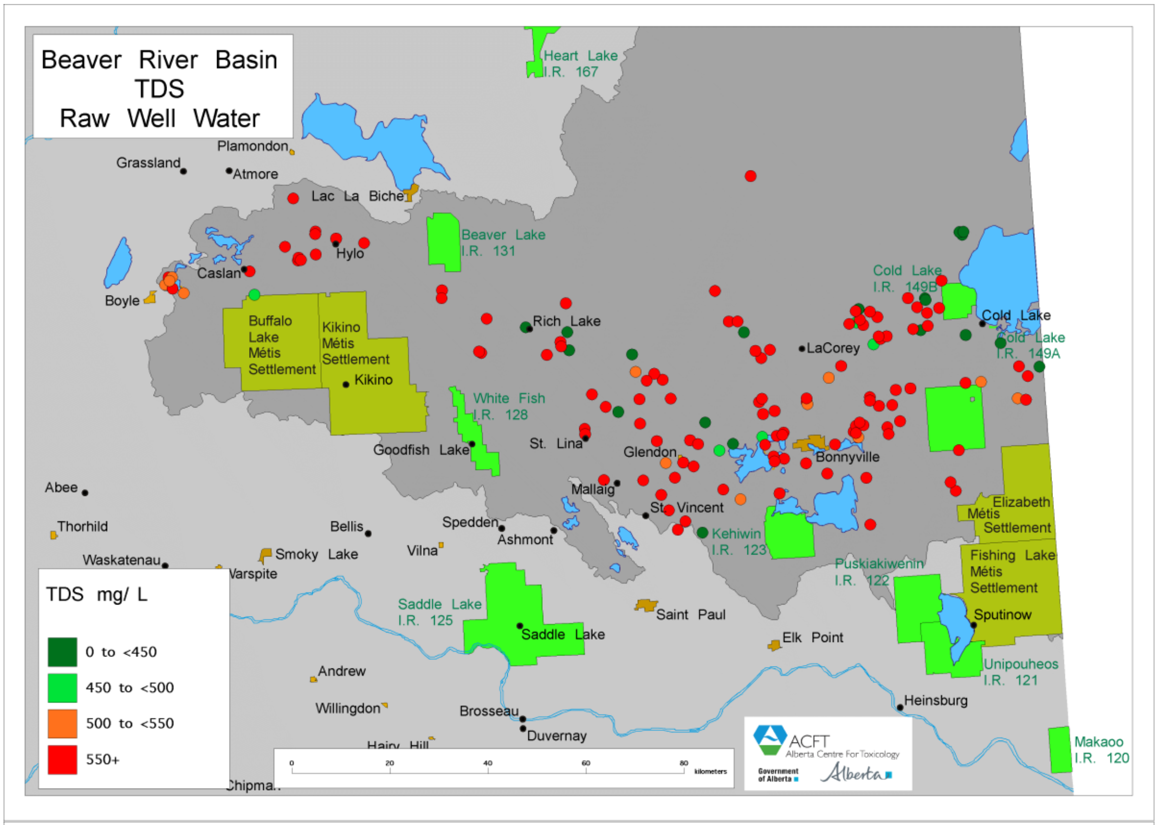


Figure 11 Spatial Patterns of EC before and after treatment



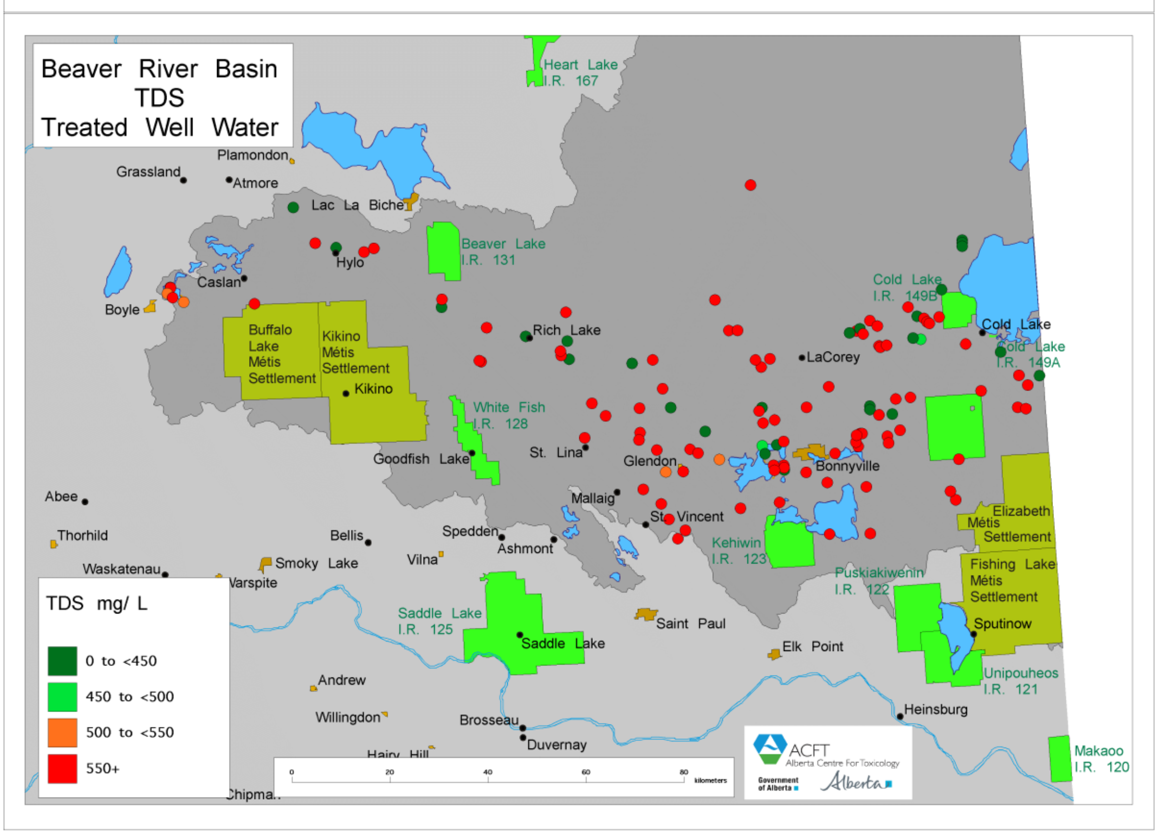


Figure 12 Spatial Patterns with Respect to TDS Guideline before and after Treatment

The guideline for TDS refers to a taste panel reference which classified taste quality as: excellent if TDS is less than 300 mg/L, good if TDS is between 300 and 600 mg/L, fair if TDS is between 600 and 900 mg/L, poor if TDS is between 900 and 1200 mg/L, and unacceptable taste if TDS is greater than 1200 mg/L (Health Canada 1991).

The overall suitability of domestic well water for human drinking on the basis of taste was found as

Rate	Value	Raw Water	Treated Water
excellent	<300 mg/L	3%	17%
good	300 – 600 mg/L	29%	15%
fair	600 – 900 mg/L	23%	23%
poor	900 – 1,200 mg/L	20%	20%
unacceptable	>1,200 mg/L	25%	25%

The results indicated that the majority of raw and treated water (55 per cent) was rated as excellent to fair for human consumption based on taste. About 25 per cent of raw and treated water would not be suitable for human consumption based on taste. The higher levels of TDS may also cause hardness of water, scaling problems (i.e, mineral deposition) or corrosion (Health Canada 1991).

3.3.3 Hardness, Calcium, Magnesium

- ✓ Domestic well water is classified as very hard water in this region (92 per cent of raw well samples)
- ✓ Soft water occurred in 0.7 per cent of raw well samples, but soft water occurred in 80 per cent of treated well samples after using softeners
- ✓ An optimal level for balancing corrosion and scale problem was found in none of well samples

Hardness

The mean and median observed for hardness were 536 and 484 mg/L with a range of 3.8 –1,170 mg/L in raw water samples, and 88 and 12 mg/L with a range of 0.02 -1,002 mg/L in treated water samples, respectively (Table 5). A typical range of hardness in groundwater is from 10 to 500 mg/L expressed as $CaCO_3$ (Younger 2007).

A total of 103 household who used softeners to treat water submitted raw and treated samples (Table B in Appendix D). Hardness levels were reduced significantly after using softeners (p <0.001) (Figure 13 and 14). The reduction range was from 61 to 100 per cent in 93 per cent of households.

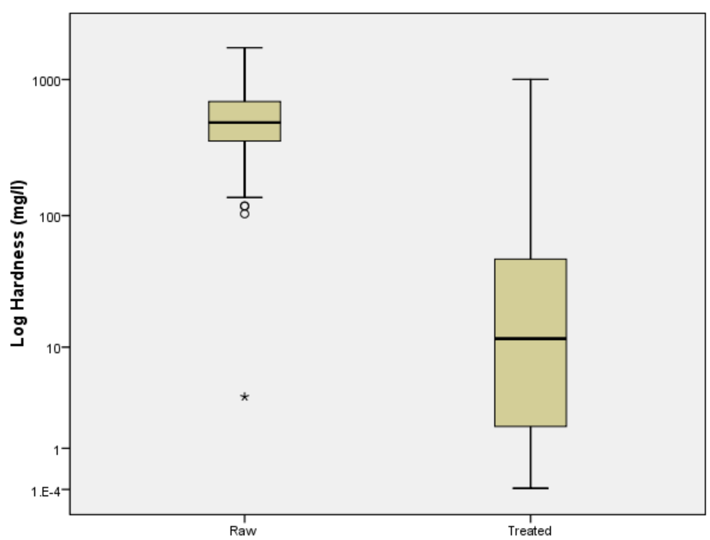


Figure 13 Distribution for Hardness

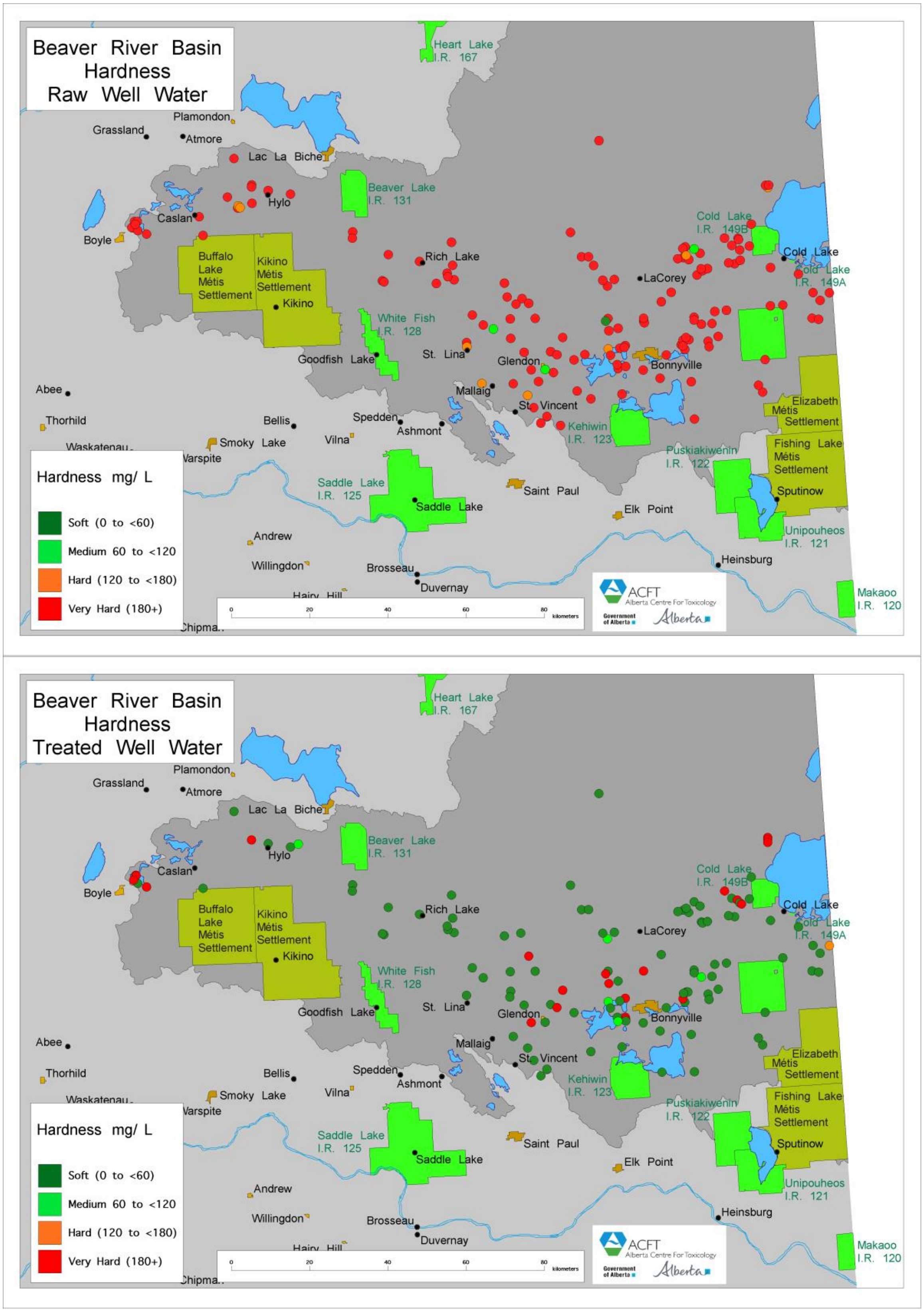


Figure 14 Spatial Patterns of Hardness Classes before and after Treatment

There is no guideline for hardness in Canada. Public acceptability of the degree of hardness varies greatly from one community to another. Hardness in the water can be classified among four levels (Health Canada 1979):

1. soft at a level less than 60 mg/L (as $CaCO_3$);
2. medium hard at the levels between 60 – 120 mg/L;
3. hard at the levels between 120 – 180 mg/L; and
4. very hard at a level greater than 180 mg/L.

The hardness levels in raw water samples in the BRB were found as

Rate	Value	Raw Water	Treated Water
soft water	<60 mg/L	0.7%	78.3%
Medium hard water	60 – 120 mg/L	2.0%	4.2%
Hard water	120 – 180 mg/L	5.5%	0.8%
Very hard water	> 180 mg/L	91.8%	16.7%
Optimal level of hardness	80 – 100 mg/L	0%	0.8%

After treatment, the water became soft in 80 per cent of treated water samples (97 out of 120). The optimal level of hardness is between 80 and 100 mg/L for balancing corrosion and scale problems (Health Canada 1979). Soft water tends to cause corrosion of pipes and plumbing fixtures. Hard water causes scaling of pipes, hot water heaters, humidifiers and appliances like electric kettles.

Calcium and Magnesium

The mean and median of calcium were 127 and 117 mg/L with a range of 0.9 – 420 mg/L in raw water samples, and 19 and 2.6 mg/L with a range of <0.1 – 161 mg/L in treated water samples, respectively (Table 5). The mean and median of magnesium were 53 and 46 mg/L with a range of 0.4 –192 mg/L in raw water samples, and 10 and 1.1 mg/L with a range of <0.1 – 186 mg/L in treated water samples, respectively (Table 5).Typical ranges are 10 – 500 mg/L for calcium and 5 – 400 mg/L for magnesium in groundwater (Younger 2007).

A total of 103 households used softeners to treat water. Calcium and magnesium levels reduced significantly after using softeners ($p < 0.001$) (Figure 15, 16 and 17). The range of reduction was from 58 to 100 per cent in 93 per cent households (Table B in Appendix D).

Calcium and magnesium are essential elements for human health (Health Canada 1978, 1987a). No evidence showed calcium and magnesium in drinking water can cause adverse human health effects. There are no guidelines for calcium and magnesium in Canada. If the water is naturally soft or softened, it may have less calcium and magnesium. Studies have shown that consuming sufficient calcium and magnesium may have benefits for preventing cardiovascular disease (Monarcar et al. 2006). Drinking water is one of sources of calcium although there are major dietary sources of these elements such as dairy products.

Calcium and magnesium are the major sources of hardness so their sum is strongly correlated with hardness. Because they cause hardness, high levels of calcium and magnesium can cause scaling problems in the plumbing fixtures and household appliances.

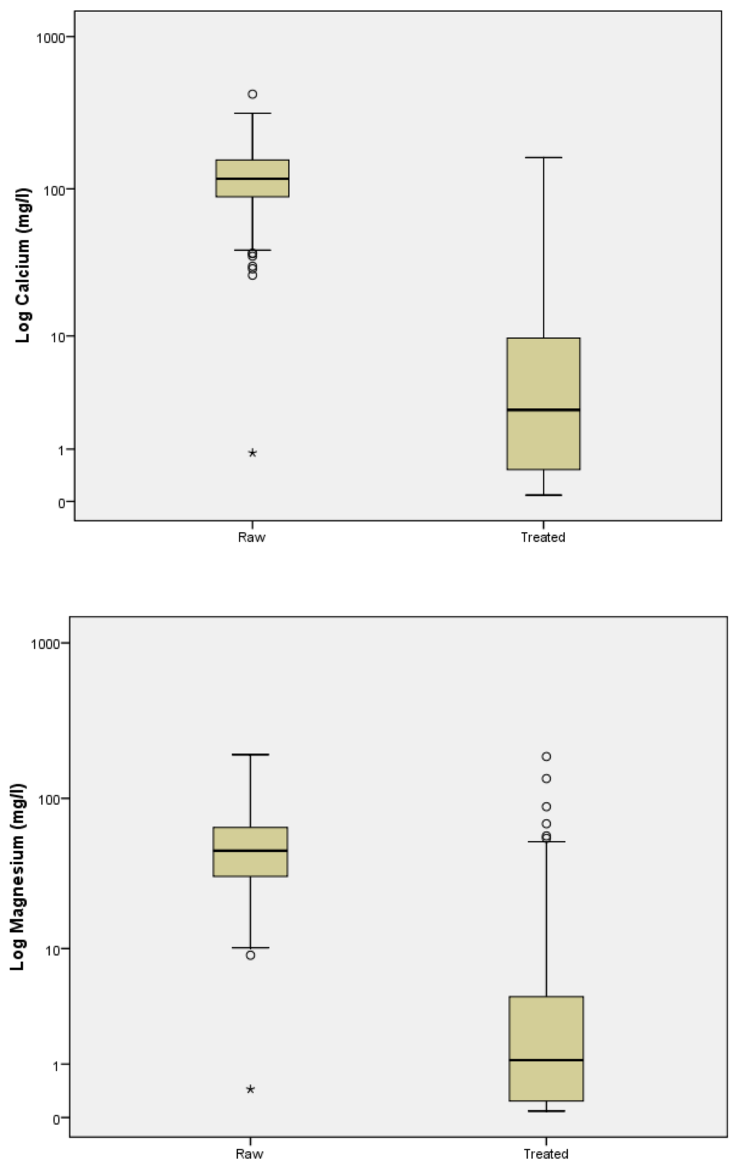


Figure 15 Distribution of Calcium and Magnesium

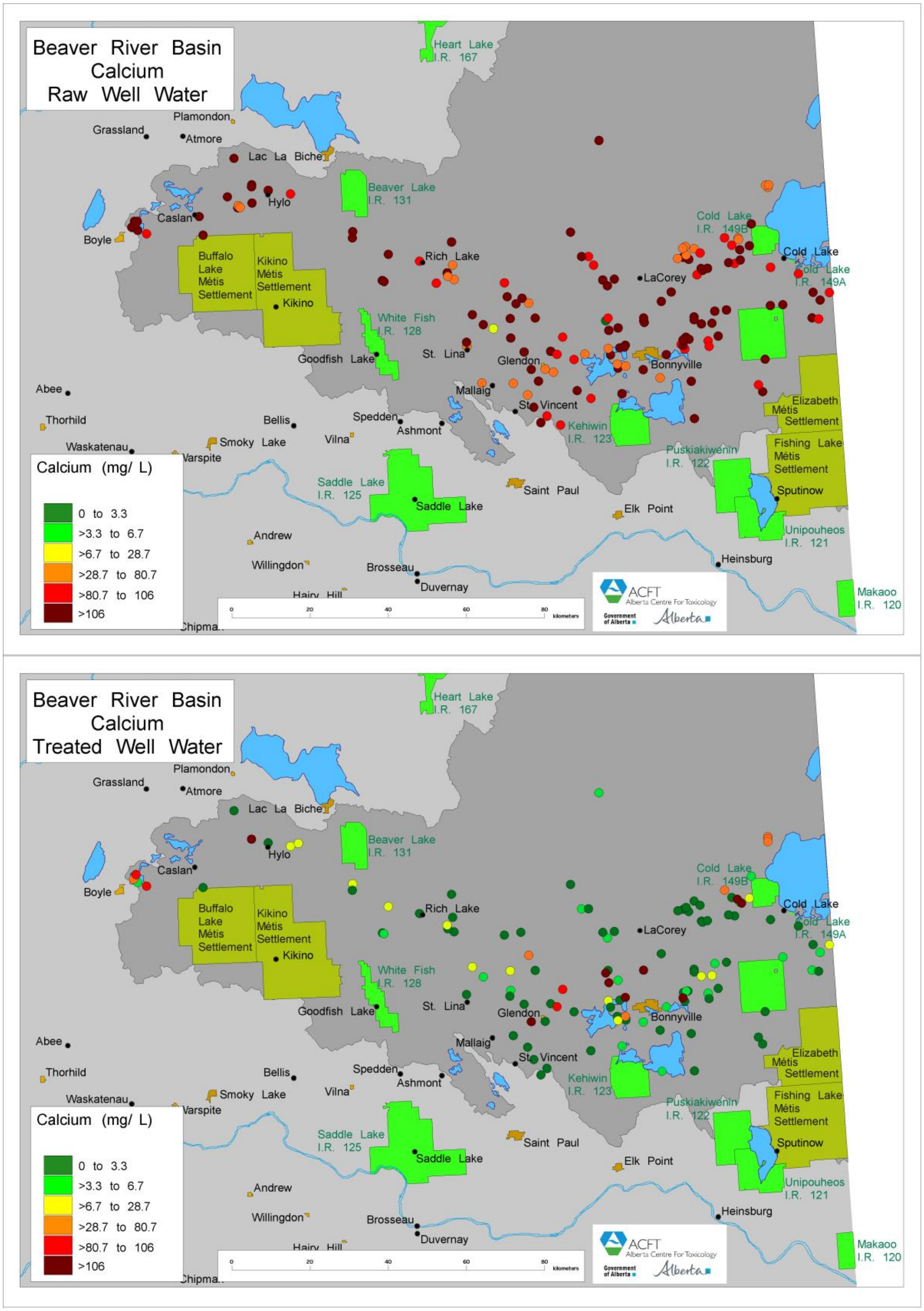


Figure 16 Spatial Patterns of Calcium before and after Treatment

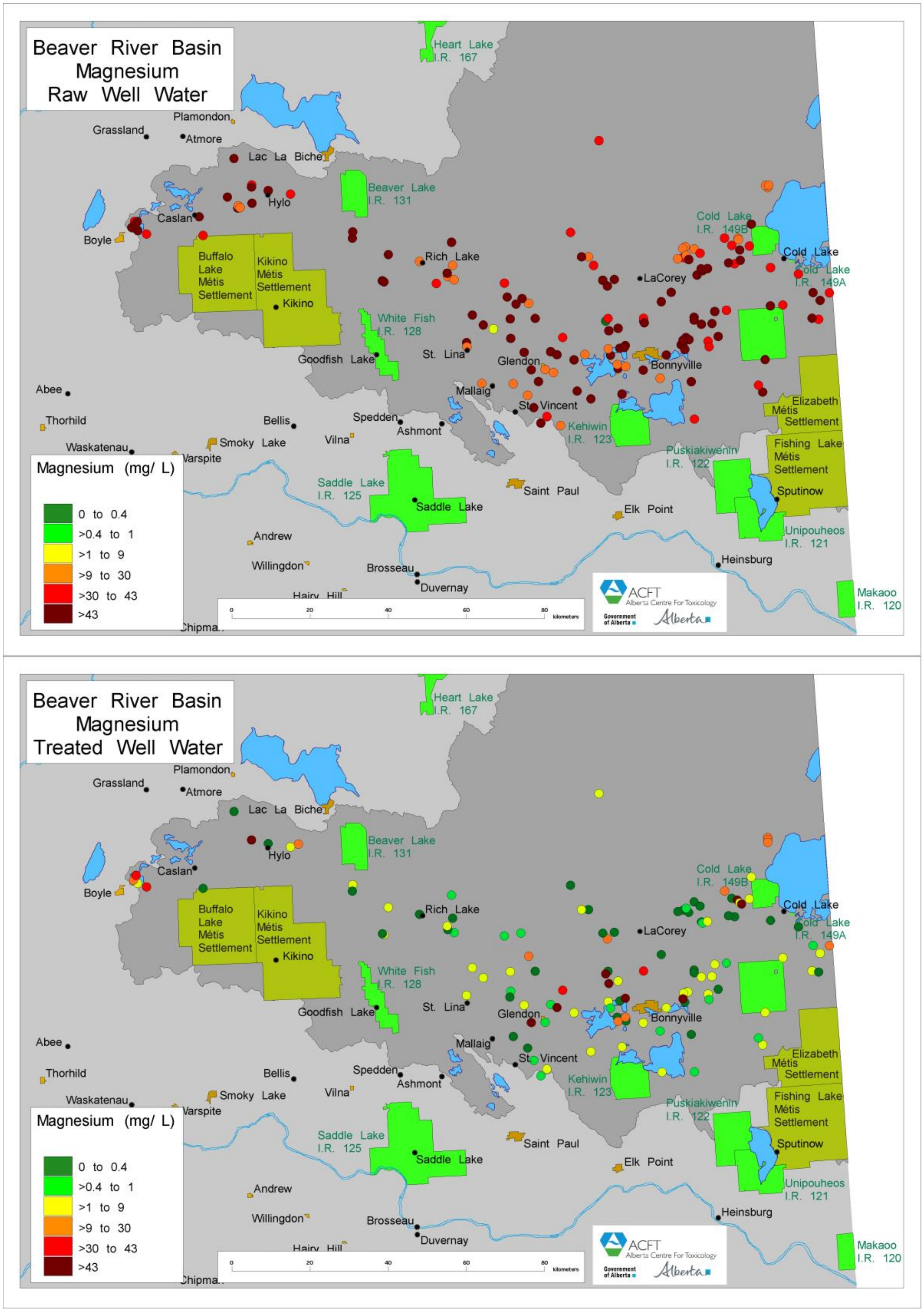


Figure 17 Spatial Patterns of Magnesium before and after Treatment

3.3.4 Bicarbonate and Carbonate

✓ The levels of bicarbonate were decreased and carbonate levels increased after treatment.

Bicarbonate

The mean and median of bicarbonate were 650 and 661 mg/L with a range of 136 – 964 mg/L in raw water samples, and 556 and 633 mg/L with a range of 1.6 – 976 mg/L in treated water samples, respectively (Table 5).

Bicarbonate is a major form of alkalinity which is also closely linked to hardness. Bicarbonate ions are dominant in water with pH between 6.0 and 8.5. The bicarbonate levels changed statistically significantly before and after treatment in the samples collected from 19 households ($p < 0.001$). There was a considerable reduction (82 to 100 per cent) of the bicarbonate levels in these samples (Table A in Appendix D). Out of 19 households, reverse osmosis unites were used in 11 households, iron filter in nine households, distillers in seven households and softener in 18 households. In these households, combined treatment methods were used.

Carbonate

The mean and median of carbonate were 0.7 and 0 mg/L with a range of 0 – 21 mg/L in raw water samples, and 3.7 and 0 mg/L with a range of 0 – 83 mg/L in treated water samples, respectively (Table 5). After treatment, carbonate levels increased as bicarbonate levels decreased ($p <0.001$) (Figure 18, 19 and 20).

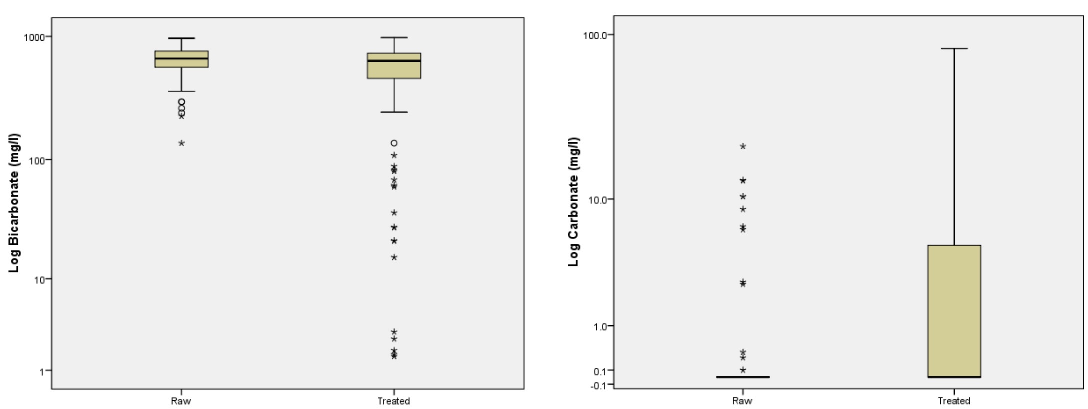


Figure 18 Distribution of Bicarbonate and Carbonate

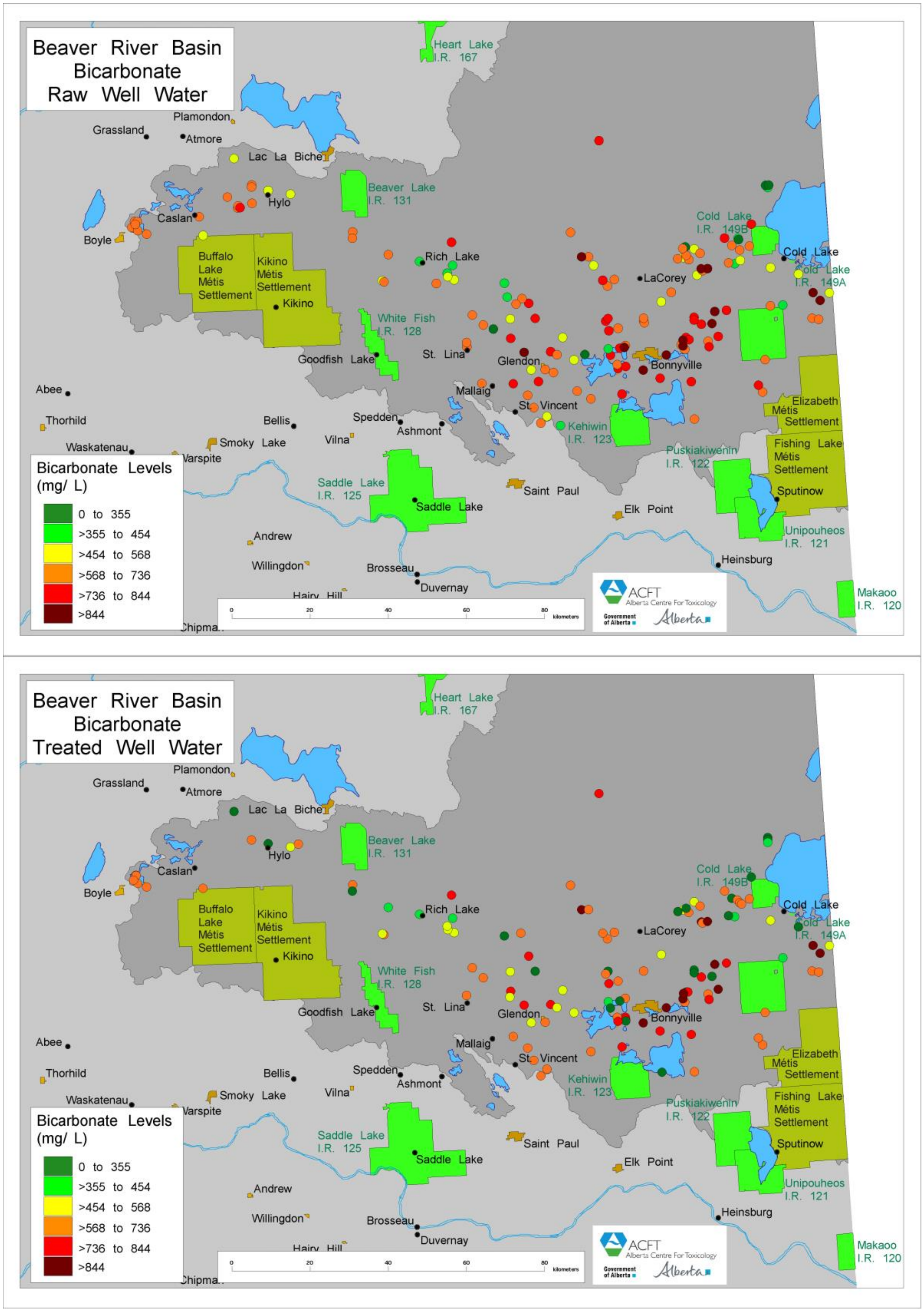


Figure 19 Spatial Patterns of Bicarbonate before and after Treatment

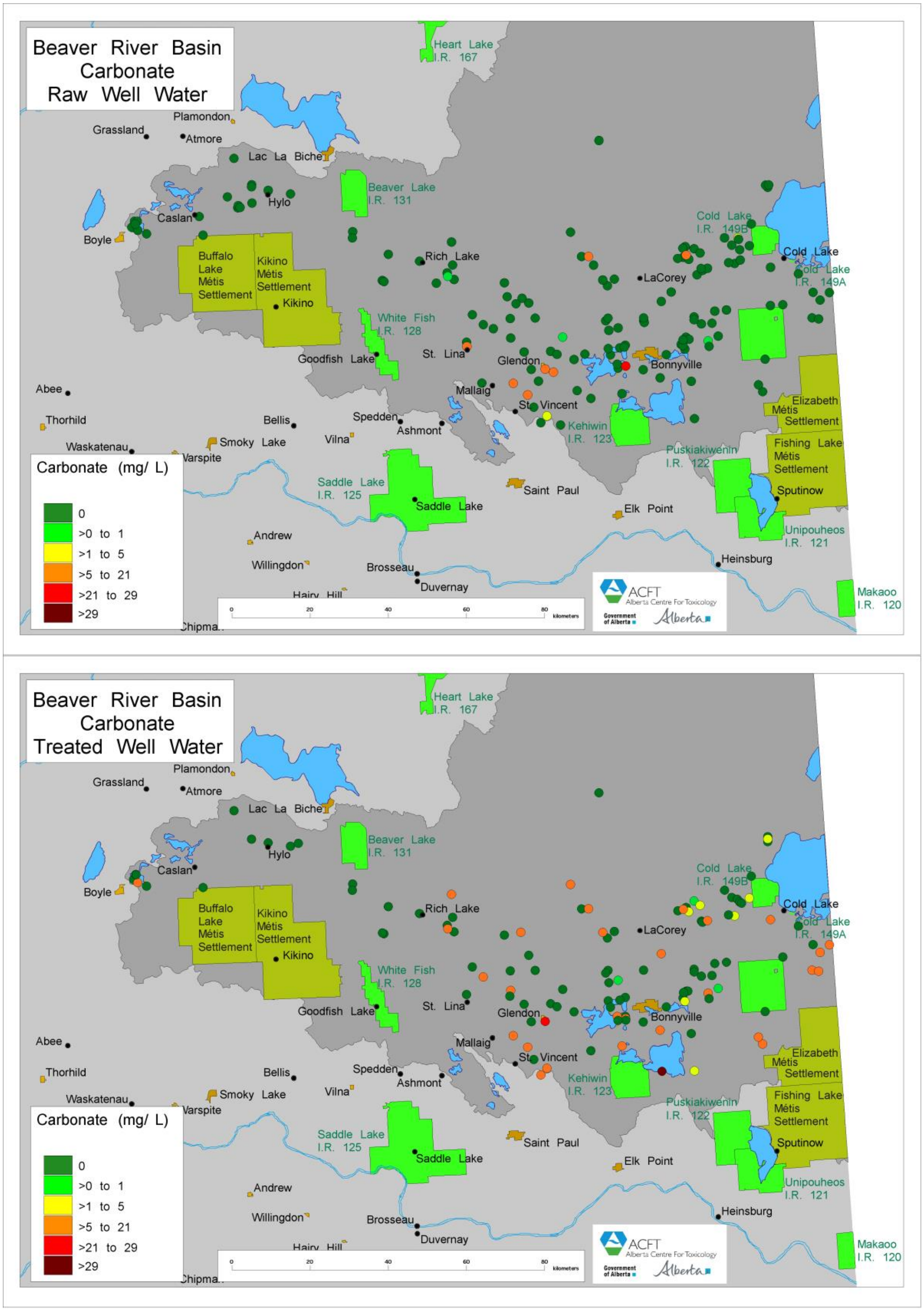


Figure 20 Spatial Patterns of Carbonate before and after Treatment

3.3.5 Sodium

- ✓ The sodium levels exceeded the Canadian aesthetic quality guideline in 20.5 per cent of raw water samples and in 47.5 per cent of treated water samples after using softeners

The mean and median of sodium were 136 and 85 mg/L with a range of 3.6 – 895 mg/L in raw water samples, and 230 and 195 mg/L with a range of <1.0 - 1088 mg/L in treated water samples, respectively (Table 5). Typical levels of sodium in groundwater in Canada ranged from 6 to 130 mg/L (Health Canada 1979b).

Sodium levels increased significantly after treatment (p <0.001) (Figure 21 and 22). Softeners were used to treat hard water in 103 households (Table C in Appendix D). The average of sodium levels increased in 66 per cent of households and decreased in 34 per cent households. Significant reduction of sodium levels was observed in 11 households by using reverse osmosis unites, four households by using distiller and two households by using iron filter. The decreased sodium levels and increased potassium levels at the same time were observed in 21 households. The decreased potassium levels and increased sodium levels at the same time were observed in 43 households.

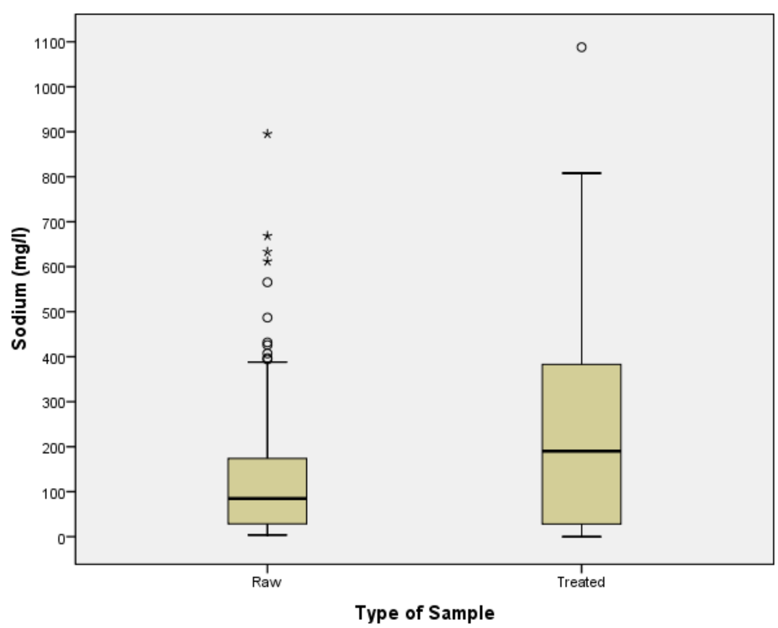


Figure 21 Distribution of Sodium

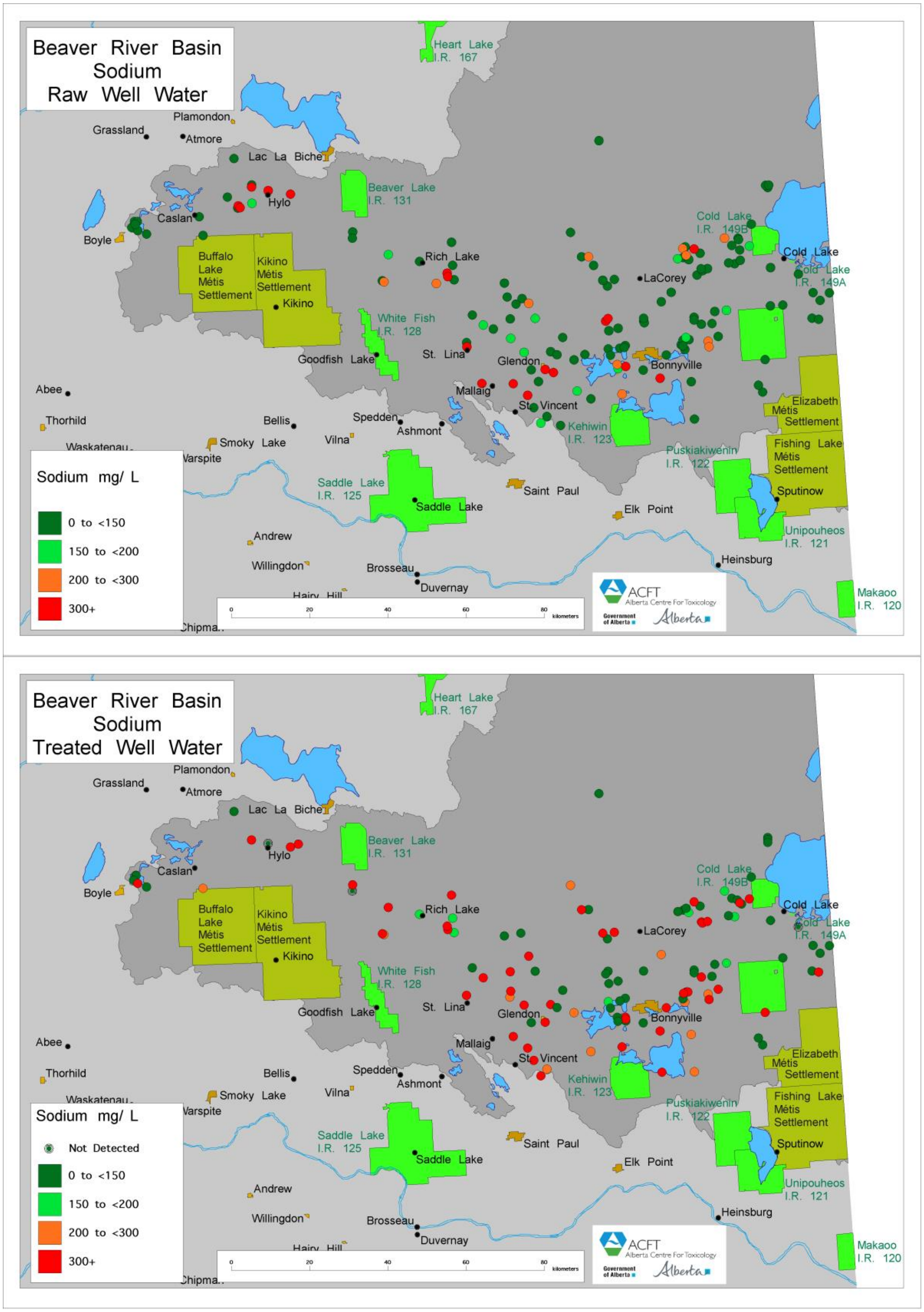


Figure 22 Spatial Patterns with Respect to Sodium Guideline before and after Treatment

The guideline for sodium related to aesthetic quality in drinking water in Canada is 200 mg/L or less. Sodium greater than 200 mg/L can impart an unpleasant saline taste. Sodium levels exceeded the guideline value in 20.5 per cent of raw water samples (Table 6). Sodium levels exceeded the guideline value in 47.5% of treated water samples. In the BRB region, groundwater is generally very hard and softeners are being used to treat the water in 91 per cent of surveyed households. In the softening process, either sodium or potassium levels rise because the water softener uses a medium that serves to exchange "ions" of calcium and magnesium with sodium or potassium.

High intake of sodium from food and drinking water will increase the risk of occurrence of hypertension, heart failure and other health conditions (Health Canada 1979b).

3.3.6 Chloride

✓ The chloride levels were under the aesthetic guideline value in 90 per cent of raw water samples

The mean and median of chloride were 86 and 17 mg/L with a range of 0.7 – 1,415 mg/L in raw water samples, and 69 and 14 mg/L with a range of < 1.0 – 1,528 mg/L in treated water samples, respectively (Table 5). A typical worldwide range of chloride in groundwater is 10 – 1000 mg/L (Younger 2007). Chloride levels were not significantly different before and after water treatment ($p > 0.05$) (Figure 23).

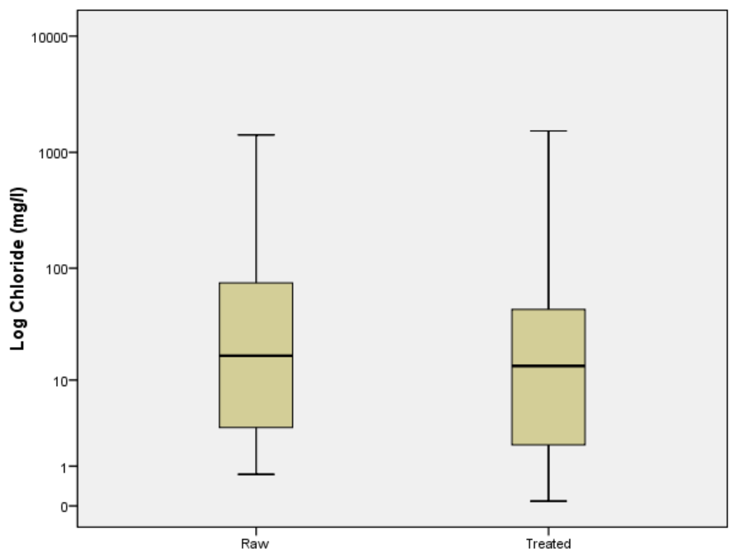


Figure 23 Distribution of Chloride

The Canadian guideline for chloride related to aesthetic quality in drinking water in Canada is 250 mg/L or less. Chloride greater than 250 mg/L can impart an unpleasant saline taste and may cause corrosion in the plumbing system. In the BRB region, chloride levels were under this guideline value in 90 per cent of raw water samples and 92.5 per cent of treated water samples (Table 6, Figure 24).

Chloride is an essential element for human health. Chloride intake at about 600 milligrams per day is considered as adequate for good health, but only 0.25 per cent of chloride intake has been found to come from drinking public water supplies (Health Canada 1979c).

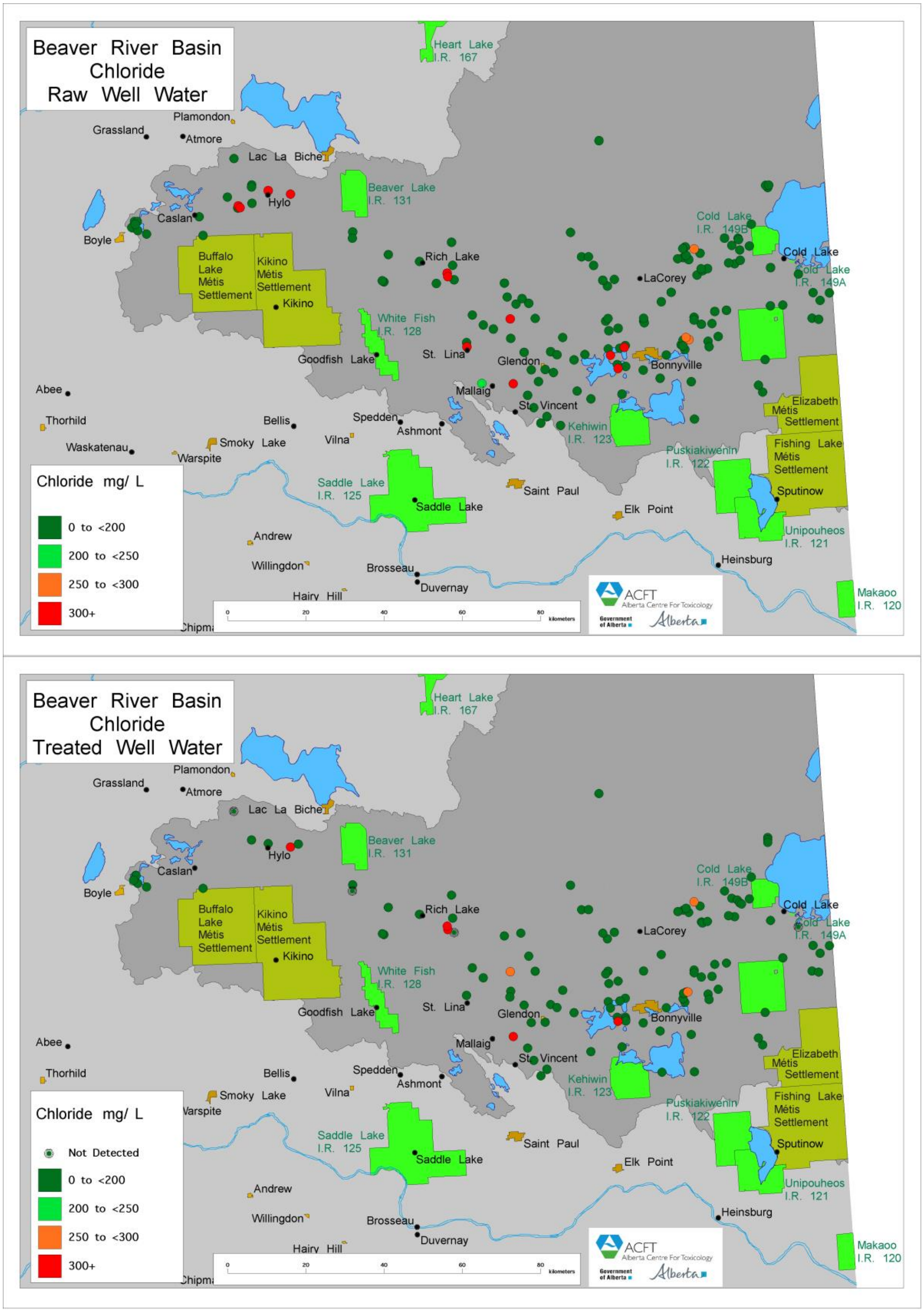


Figure 24 Spatial Patterns with Respect to Chloride Guideline before and after Treatment

3.3.7 Sulfate

✓ The sulfate levels were under the guideline value in 89 per cent of raw water samples and 90.8 per cent of treated water samples

The mean and median of sulfate were 199 and 109 mg/L with a range of <1.0 mg/L – 1474 in raw water samples, and 179 and 91 mg/L with a range of <1.0 – 1,387 mg/L in treated water samples, respectively (Table 5). A typical worldwide range of sulfate in groundwater is 10 – 500 mg/L (Younger 2007). Sulfate levels were not significantly different before and after treatment ($p > 0.05$) (Figure 25).

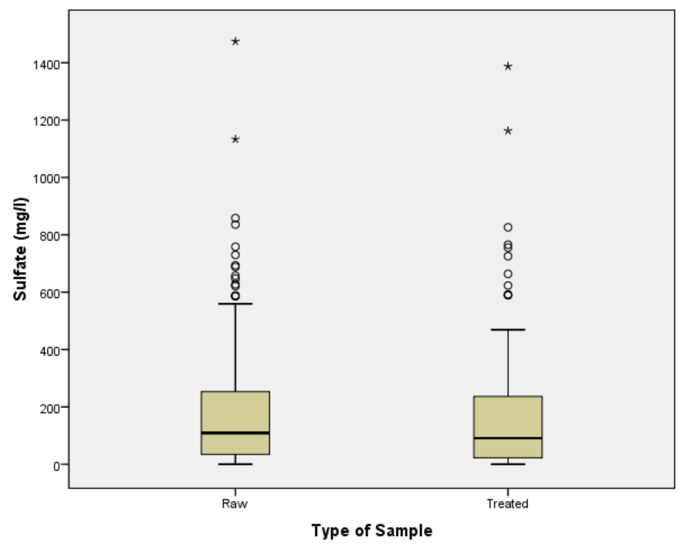


Figure 25 Distribution of Sulfate

The Canadian guideline for sulfate related to aesthetic quality in drinking water in Canada is 500 mg/L or less. In the BRB region, sulfate levels were under this guideline in 89 per cent of raw well samples and 90.8 per cent of treated water samples (Table 6, Figure 26).

Sulfate is not a health hazard at typical levels in groundwater. But some people, particularly infants, may experience diarrhea or gastrointestinal irritation when the sulfate levels are very high (>1000 mg/L). Sulfate greater than 500 mg/L can impart an unpleasant taste or cause corrosion. High levels of sulfate can also support sulfate bacteria which can produce a dark slime and clog plumbing. Sulfate-reducing bacteria also produce sulfide which imparts a rotten egg odor if released as hydrogen sulfide (Health Canada 1987b). Sulfide has an aesthetic-based odor guideline of only 0.05 mg/L allowing it to cause a nuisance at very low levels. Water under reducing conditions will often exhibit a sulfide odor.

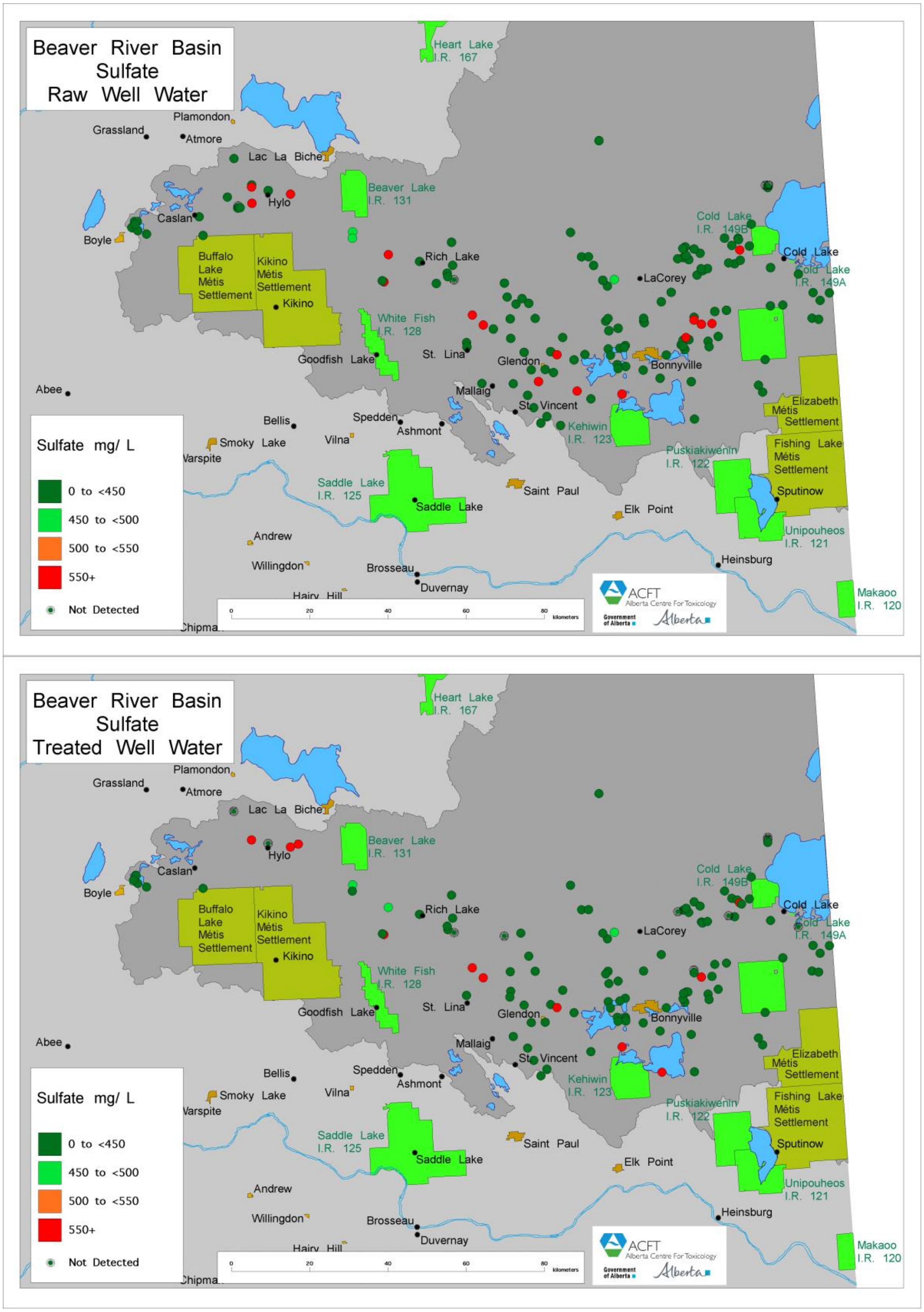


Figure 26 Spatial Patterns with Respect to Sulfate Guideline before and after Treatment

3.3.8 Potassium

> ✓ Potassium levels increased in treated water samples in 33 per cent of houses and decreased in treated water samples in 52 per cent of houses after using softeners

The mean and median of potassium were 5.4 and 5.0 mg/L with a range of 1.2 – 18 mg/L in raw water samples, and 107 and 3.5 with a range of <0.1 – 1,150 mg/L, respectively (Table 5). A typical worldwide range of potassium in groundwater is 1 – 50 mg/L (Younger 2007).

The average level of potassium significantly increased before and after treatment ($p < 0.001$), but the median of potassium level was lower after treatment (Figure 27 and 28). In 103 households, potassium levels increased in 33% per cent of households and decreased in 52 per cent of households (Table C in Appendix D), The average levels of potassium in raw well samples reflect the levels from natural-occurring sources. The significantly increased potassium levels in treated water samples after treatment were likely due to the use of softeners based on potassium chloride.

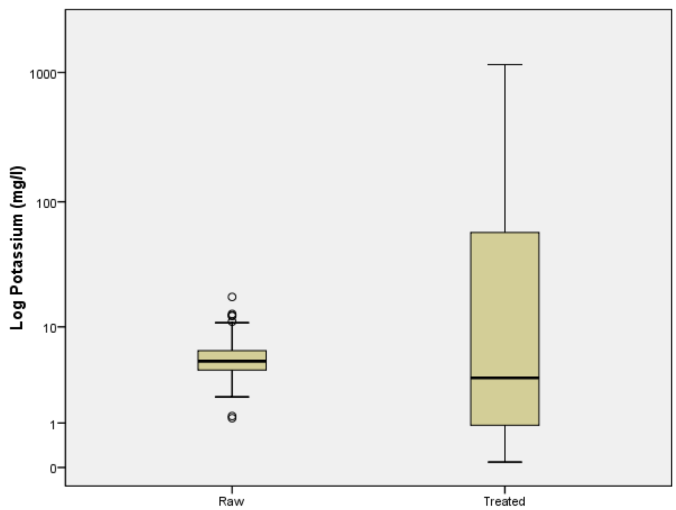


Figure 27 Distribution of Potassium

No health risk is posed by exposure to potassium at the levels detected in groundwater. There is no Canadian drinking water guideline for potassium. However, potassium levels could increase when people use potassium-containing softeners to treat hard water. High intake of potassium from drinking water may pose a potential health risk to people with underlying health conditions such as kidney dysfunction and heart dysfunction. In this case, people with kidney and heart conditions should consult with their family physicians. Health Canada proposed the strategies to reduce potassium exposure for human consumption when potassium-containing water softener is used for hard water treatment (Health Canada 2008). One approach is to have the water bypass the softener altogether. Another approach is to use technology to remove potassium residue in the water when combined with the water softening treatment.

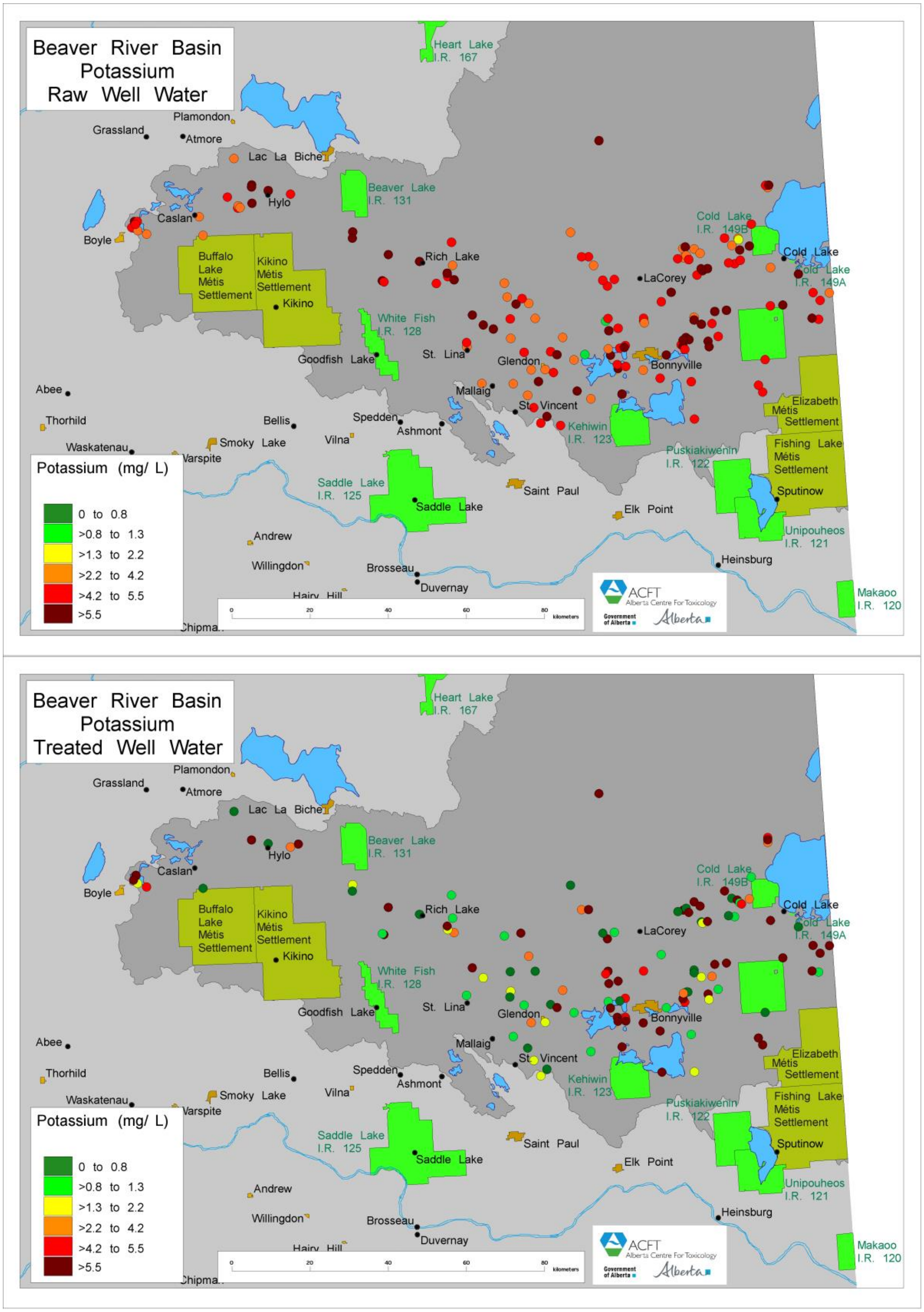


Figure 28 Spatial Patterns of Potassium before and after Treatment

3.3.9 Iron

- ✓ Iron levels in 71 per cent of raw water samples exceeded the guideline value
- ✓ Iron levels in 7.5 per cent of treated water samples exceeded the guideline value
- ✓ Iron can be efficiently removed by using reverse osmosis units, iron filters, distillers and softeners.

The mean and median of iron were 2.0 and 1.0 mg/L with a range of <0.01 – 17 mg/L in raw water samples, and 0.09 and 0.04 mg/L with a range of <0.01 – 1.9 mg/L in treated water samples, respectively (Table 5). The average level of iron significantly decreased after water treatment ($p < 0.001$) (Figure 29).

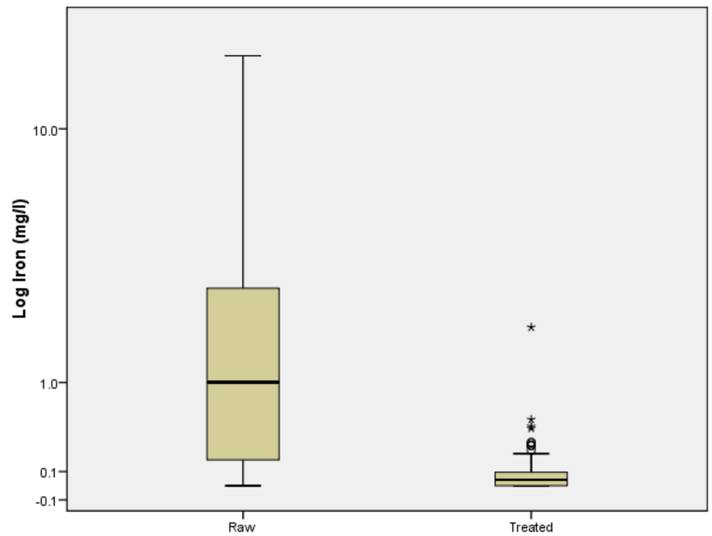


Figure 29 Distribution of Iron

The Canadian guideline for iron related to aesthetic quality in drinking water is less than 0.3 mg/L. Iron greater than 0.3 mg/L can impart an unpleasant taste and colour of water, and may cause the staining of plumbing fixtures, laundry and household appliances. Iron can promote the growth of iron-reducing bacteria that form a slimy coating in water distribution pipes when iron levels are greater than 0.3 mg/L.

In the BRB region, iron levels exceeded the guideline value in 71 per cent of raw water samples (Table 6). After water treatment, iron levels exceeded the guideline value in 7.5 per cent of treated water samples (Figure 30). The treatment methods and iron levels are shown in Table D of Appendix D. Iron levels were completely reduced to non-detected levels by using reverse osmosis units in 11 households and distillers in seven houses. Iron levels were reduced to 75 – 100 per cent by using iron filters in 39 households. Iron levels were not reduced by using iron filters in three households. Iron levels were reduced to 80 –100 per cent by using softeners, without using reverse osmosis units, iron filters or distillers in 45 households.

This survey indicated that Iron was efficiently removed by using treatment methods such as reverse osmosis units, iron filters and distillers. Small to moderate amount of iron can be removed by a water softener because the iron cation can be exchanged with sodium in an ion exchange softener. When using a softener to remove iron, the precipitated iron may form a jelly-like substance on the inside of the water softener which will reduce the softening capability. When the owners use a water softener for iron removal, they should select the softeners which can be set to regenerate every few days, or use an automatic resin cleaning system.

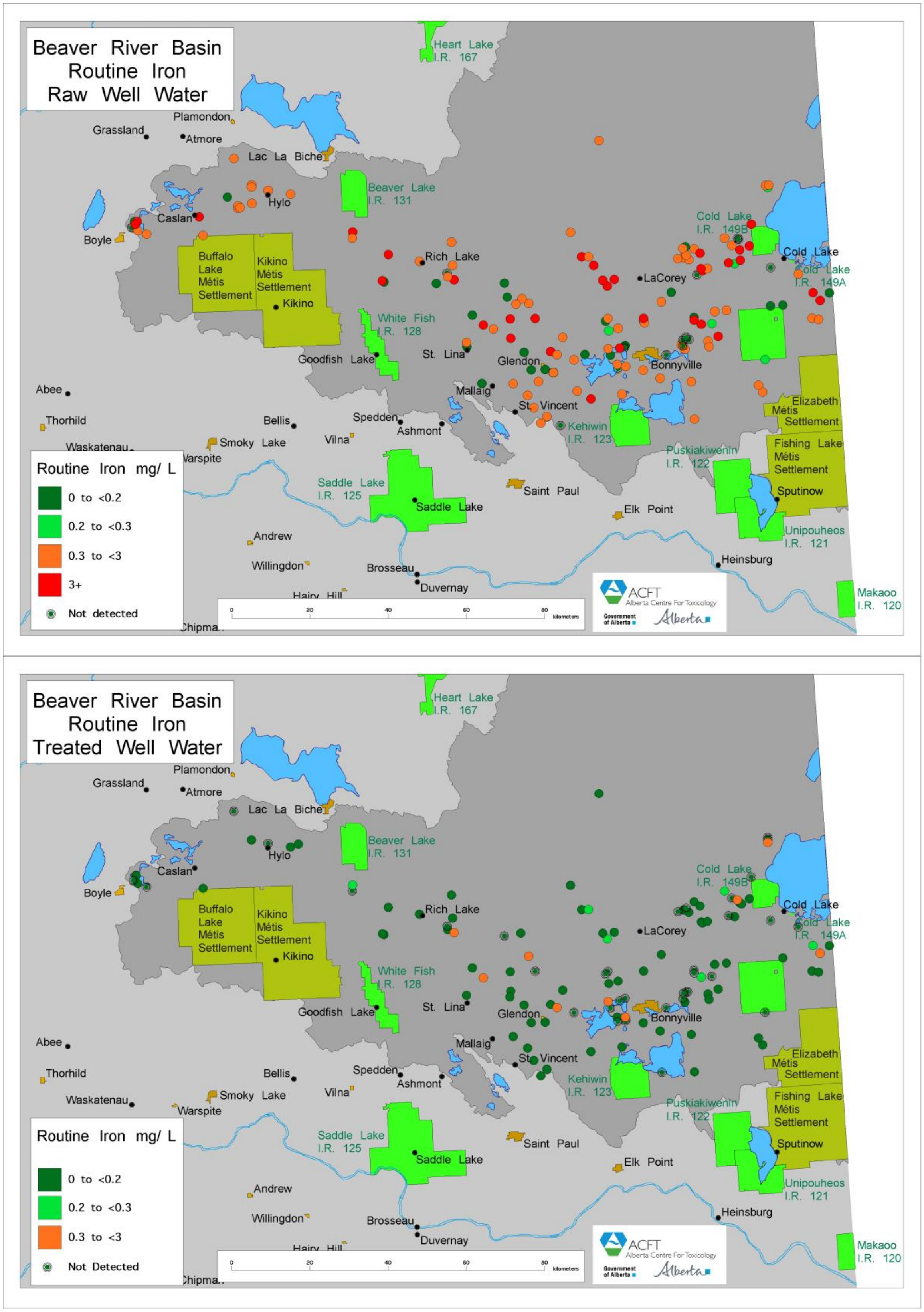


Figure 30 Spatial Patterns with Respect to Iron Guideline before and after Treatment

3.3.10 Fluoride

✓ The fluoride levels were lower than 0.8 mg/L in all the raw and treated samples.

The mean and median of fluoride were 0.3 and 0.2 mg/L with a range of 0.1 – 0.5 mg/L in raw water samples, and 0.2 and 0.2 mg/L in the treated water samples with a range of <0.1 – 0.6 mg/L, respectively (Table 5). A typical worldwide range of fluoride in groundwater is 0.3 – 3 mg/L (Younger 2007). The median level of fluoride was similar before and after treatment (Figure 31). In the BRB region, the fluoride levels in domestic well water were less than 0.8 mg/L in all the raw and treated samples (Table 6 and Figure 32).

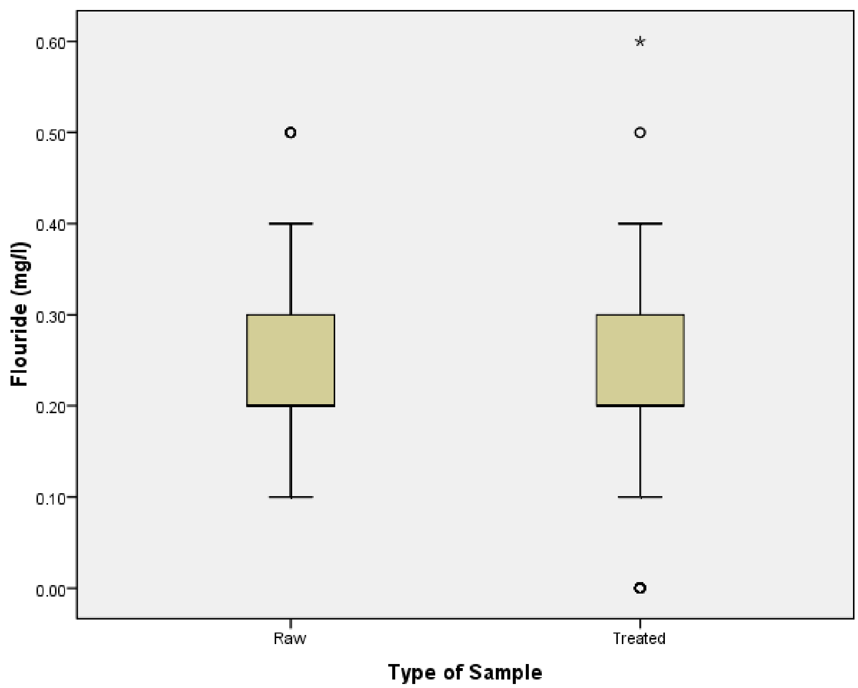
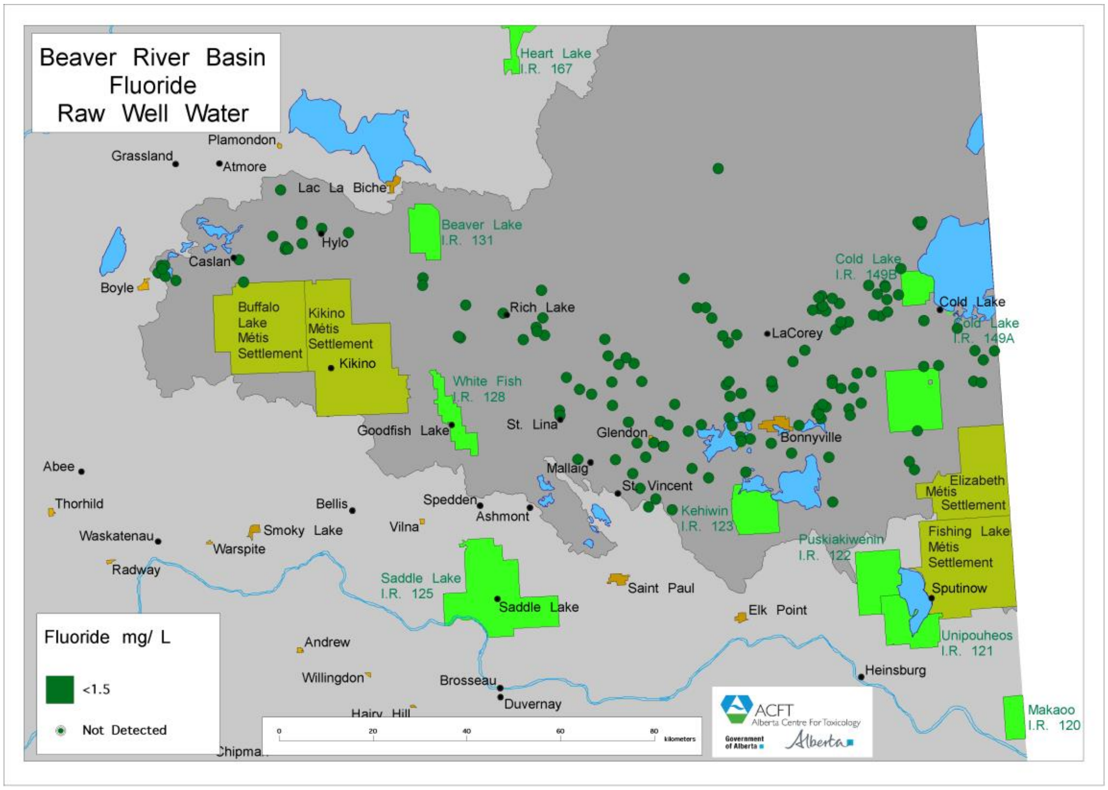


Figure 31 Distribution of Fluoride

Fluoride is a beneficial element for human dental health. Specifically, fluoride is effective for preventing dental cavities in young children up to six years old during the period of their tooth formation by exposing them to optimal levels of fluoride 0.8-1.0 mg/L in drinking water. The fluoride levels in the domestic well water in the Beaver River Basin region were lower than this optimal level considered by Health Canada (Health Canada 1998a). If there are young children in the household, the owners should consult with a dentist about use of fluoride-containing toothpaste or mouthwash as well as routine dental treatments of fluoride.



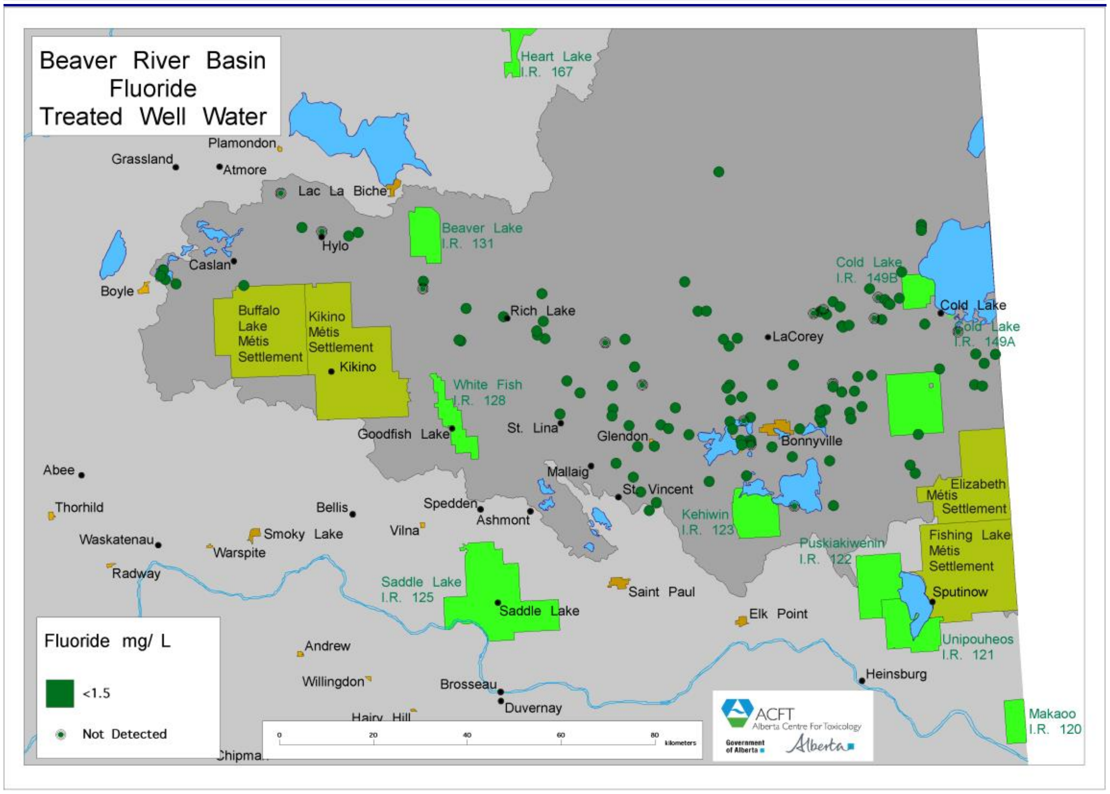


Figure 32 Spatial Patterns with Respect to Fluoride Guideline before and after Treatment

3.3.11 Nitrate and Nitrite

- ✓ Nitrate and nitrite levels were under the guideline in 96 per cent of raw water samples

The mean and median of nitrate-nitrogen (nitrate-N) were 1.5 and <1.0 mg/L with a range of <1.0 to 31 mg/L in raw water samples, and 1.4 and <1.0 mg/L with a range of <1.0 and 31 mg/L in treated water samples, respectively (Table 5). The mean and median of nitrite-nitrogen (nitrite-N) were 0.1 and <0.1 mg/L with a range of <0.1 to 2 mg/L in raw water samples, and <0.1 and <0.1 mg/L with a range of <0.1 and 0.3 mg/L in treated water samples, respectively (Table 5). A typical worldwide range of nitrate-N in groundwater is <2 – 15 mg/L (Younger 2007). Nitrate-N levels did not change significantly before and after treatment ($p=0.8$) and nitrite levels changed significantly before and after treatment ($p<0.001$) (Figure 33).

The nitrate-N levels less than 10 mg/L and nitrite-N less than 1 mg/L were found in 96 per cent of the raw and treated water samples (Figure 34, 35). When the levels of nitrate and nitrite were above the guideline values, the owners were received the letter from Alberta Health and Wellness to resubmit the second samples for chemical analysis and advice on examining the potential causes of contamination.

Some human sources such as fertilizer application, animal production (feedlots and livestock waste), and wastewater disposal (human sewage, industrial waste and food processing waste) can increase the levels of nitrate/nitrite in groundwater (Health Canada 1987c). In the BRB survey, nitrate levels greater than 10 mg/L were found in five households. The distances between setback of the well to septic tank, manure storage and animal pen are listed as

House	**Nitrate** mg/L	**Distance to Septic Tank** meter	**Distance to Animal Pens** meter
1	10	100	20
2	11.2	50	150
3	12	150	no
4	29	400	400
5	30.6	24	24

Nitrate is the only nutrient in groundwater with a specific and acute health concern because nitrate and nitrite combines with the hemoglobin in the blood to form methemoglobin. Methemoglobin reduces the vital oxygen transport capacity of hemoglobin. This condition is called methemoglobinemia or in infants “blue baby syndrome”. High methemoglobin levels can lead to digestive and respiratory problems, anoxia, brain damage or even death with severe-enough exposure.

During pregnancy, it is common for methemoglobin levels of the pregnant women to increase from normal to a maximum of 10 per cent in the 30th week of pregnancy. Pregnant women are particularly susceptible to methemoglobinemia and they should be sure that the nitrate and nitrite in the well water are at safe levels.

Once diagnosed, methemoglobinemia can be readily reversed, although if serious anoxia has occurred, permanent damage may result. Methemoglobinemia can be prevented by restricting consumption of nitrite and nitrate.

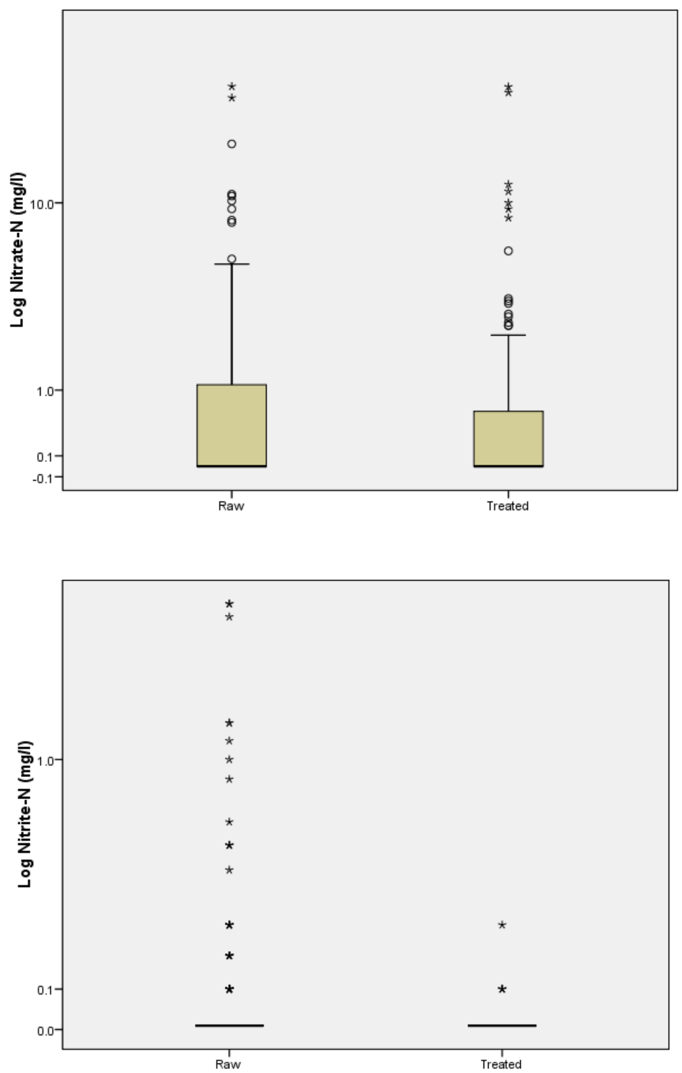


Figure 33 Distribution of Nitrate and Nitrite

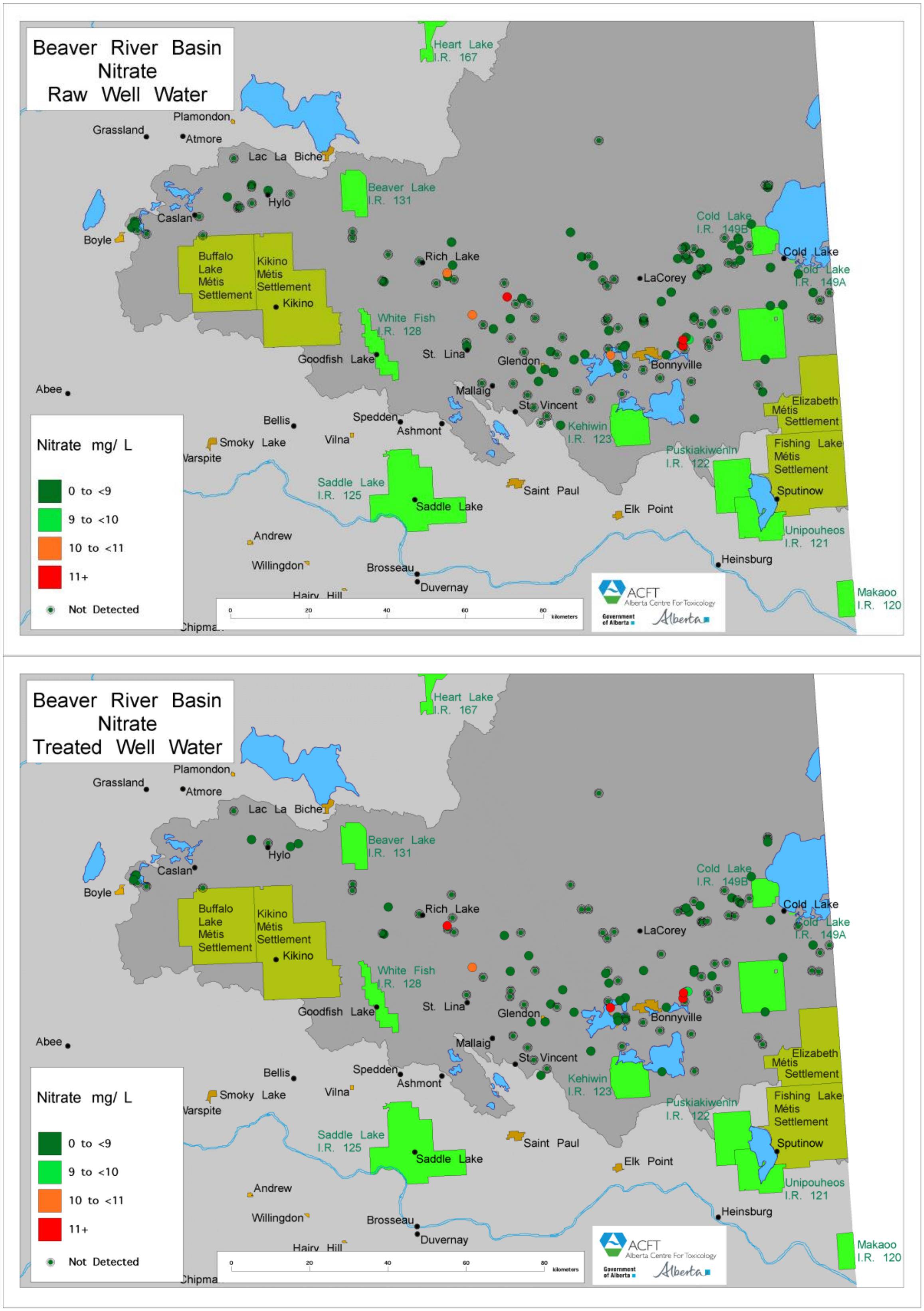


Figure 34 Spatial Patterns with Respect to Nitrate-N Guideline before and after Treatment

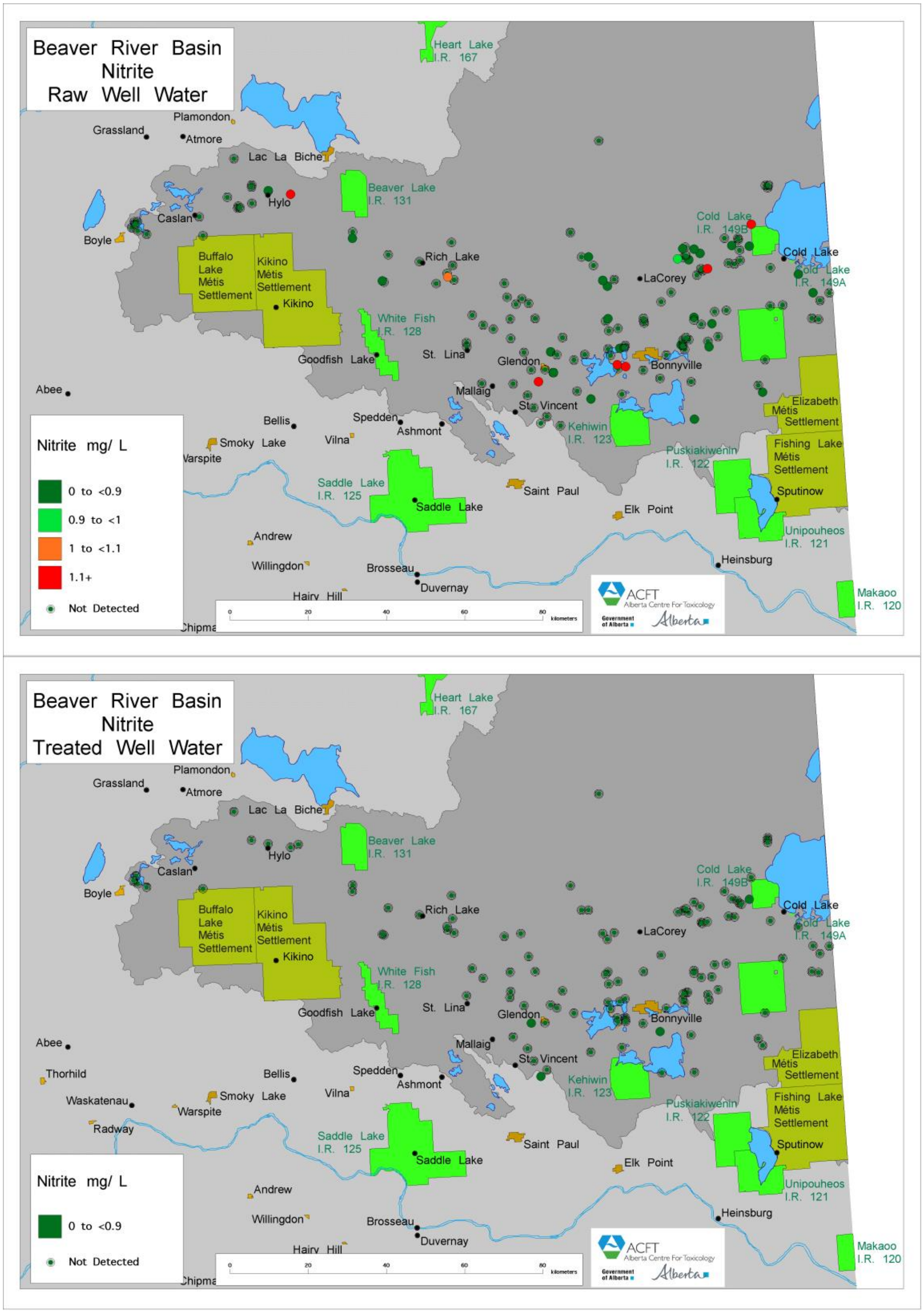


Figure 35 Spatial Patterns with Respect to Nitrite-N Guideline before and after Treatment

3.3.12 Summary – Routine Well Sample Testing

Domestic well quality varies from one region to another, depending on geological conditions at specific location. Domestic well water quality at a province level was assessed by Alberta Health and Wellness in 2010 (AHW 2010). The comparison of the median levels of physical properties and chemicals in raw water samples between the entire province and the BRB region is showed in Table 7.

Table 7 Comparison of Physical and Chemical Levels between the BRB Region and Albert

Parameter*	**Median in the BRB**	**Median in Alberta**	**Similar Level**	**Higher than Provincial Average**	**Lower than Provincial Average**
pH	8.1	8.4	X		
Alkalinity	542	488	X		
Electrical Conductivity	1323	1200	X		
Total Dissolved Solids	826	729	X		
Hardness	484	64		X	
Calcium	117	17		X	
Magnesium	46	4.5		X	
Bicarbonate	661	570	X		
Carbonate	0	7.6			X
Chloride	17	4.8		X	
Sodium	85	250			X
Sulfate	109	70		X	
Potassium	5.0	1.9		X	
Iron	1.0	0.06		X	
Fluoride	0.2	0.3	X		
Nitrate-N	<0.1	<0.1	X		
Nitrite-N	<0.1	<0.1	X		

* Unit for each parameter: Table 1.

As compared to the parameters measured in routine testing in Alberta, raw domestic water quality in the BRB region has its own characteristic:

1. overall water quality measured by using the suitability indicators of pH, alkalinity, conductivity and TDS was similar to in the provincial average;
2. aesthetic water quality by using the indicators of iron, chloride and sulfate was poorer than the provincial average;
3. hardness of water was classified as “very hard water” in the BRB region, while hardness of water was classified as “medium hard water or hard water” for the provincial average;
4. the water had less salt (sodium) than the provincial average; and
5. the levels of two health indicators of fluoride and nitrate/nitrite were similar those in Alberta.

79 per cent of private well owners treated raw domestic well water for house use including human consumption. The treatment methods include softeners, iron filters, reverse osmosis units, distiller, activated carbon filters, and chlorinators.

Changes of domestic water quality before and after water treatment are showed in Table 8:

Table 8 Comparison of Physical and Chemical Levels Before and After Treatment

Parameter*	Median before treatment	Median after treatment	Similar Level	Higher after treatment	Lower after treatment
pH	8.1	8.2	X		
Alkalinity	542	522	X		
Electrical Conductivity	1323	1354	X		
Total Dissolved Solid	826	830	X		
Hardness	484	12			X
Calcium	117	2.6			X
Magnesium	46	1.1			X
Bicarbonate	661	633	X		
Carbonate	0	0	X		
Chloride	17	14	X		
Sodium	85	190		X	
Sulfate	109	91	X		
Potassium	5.0	3.5			see #5 below
Iron	1.0	0.04			X
Fluoride	0.2	0.2	X		
Nitrate-N	<0.1	<0.1	X		
Nitrite-N	<0.1	<0.1	X		

*Unit for each parameter: Table 1

The overall water suitability was similar before and after treatment. Hardness and iron levels were significantly reduced after water treatment. Sodium levels increased two-fold. In some households, the significant changes of chemical levels were observed as below:

1. alkanility, conductivity, TDS, bicarbonate were significantly removed by using a combination of treatment methods such as reverse osmosis, iron filtration, distillation or activated carbon filtration as compared to these households which did not use a combination of treatment methods;
2. iron was efficiently removed by using iron filters, reverse osmosis units, distillers or softeners;
3. very hard water became soft water in 80 per cent of households after using softeners;
4. sodium levels were significantly increased after using softeners;
5. potassium levels were significantly increased after using softeners although the median of potassium levels decreased as averaging the levels from all households.

3.4 Trace Element Testing

- ✓ The levels of beryllium, cadmium, chromium, mercury, thallium and vanadium were not detected in any raw or treated water samples
- ✓ The levels of aluminum, antimony, barium, boron, cadmium, chromium, copper, lead, mercury, molybdenum, nickel, selenium, uranium and zinc were individually under the guideline values in 95 to 100 per cent of raw and treated water samples
- ✓ After water treatment, the levels of arsenic, barium, manganese and zinc were reduced significantly

A statistical summary of results of trace element testing is listed in Table 9. Maximum Acceptable Concentrations (MAC) for some trace elements in drinking water have been proposed by Health Canada (2009). In cases where no guidelines have been specified, the World Health Organization drinking water guidelines were referenced (WHO 2008). The guidelines included health-based and aesthetic-quality-based guidelines. The percentages of the tested domestic well water samples with the values less than the guidelines are listed in Table 10.

The summary of the results of trace element testing is listed as

1. the levels of beryllium, cadmium, chromium, mercury, thallium and vanadium were not detected (less than 0.001 mg/L) in any raw or treated water samples;
2. the levels of antimony, boron, cadmium, chromium, copper, mercury, molybdenum, nickel, selenium were individually under the guideline values in any raw or treated water samples;
3. the levels of aluminum, barium, lead, uranium and zinc were individually under the guideline values in 95 to 99 per cent of raw or treated water samples;
4. the levels of arsenic were under the guideline value in 52 per cent of raw water samples and 71 per cent of treated water samples
5. changes of trace element levels before and after water treatment were not significant for aluminum, antimony, beryllium, boron, cobalt, cadmium, chromium, copper, lead, mercury, molybdenum, nickel, selenium, silver, thallium, thallium, vanadium, and uranium ($p>0.05$);
6. after water treatment, a significant reduction ($p <0.05$) of arsenic, barium (Figure 36), manganese (Figure 37) and zinc (Figure 38); and
7. the levels of manganese were under the guideline value in 25 per cent of raw water samples and 85 per cent of treated water samples (Figure 36). Manganese often occurs together with iron in groundwater and the high levels of manganese can impart an unpleasant tastes and cause black or brown colour and staining in plumbing fixtures. The treatment methods for removing iron can also remove manganese efficiently.

Table 9 Statistic Summary in Trace Elements Testing

Parameter	**Type**	**Mean** mg/L	**Median** mg/L	**Min** mg/L	**Max** mg/L	**Percentile** (mg/L)			
						10	**25**	**75**	**90**
Aluminum	Raw	0.011	0.007	0.005	0.162	0.006	0.006	0.010	0.014
	Treated	0.008	0.007	<0.001	0.044	0.006	0.006	0.009	0.012
Antimony	Raw	0.0001	<0.001	<0.001	0.003	<0.001	<0.001	<0.001	<0.001
	Treated	0.0015	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	0.001
Arsenic	Raw	0.013	0.007	<0.001	0.055	<0.001	<0.001	0.023	0.036
	Treated	0.008	0.002	<0.001	0.045	<0.001	<0.001	0.012	0.028
Barium	Raw	0.123	0.054	<0.001	1.673	0.015	0.028	0.155	0.337
	Treated	0.179	0.001	<0.001	0.328	<0.001	<0.001	0.008	0.056
Beryllium	Raw	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	Treated	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Boron	Raw	0.263	0.210	0.040	1.02	0.070	0.110	0.330	0.529
	Treated	0.241	0.190	0.010	0.990	0.60	0.113	0.307	0.539
Cadmium	Raw	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	Treated	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Chromium	Raw	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	Treated	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cobalt	Raw	0.0002	<0.001	<0.001	0.005	<0.001	<0.001	<0.001	0.001
	Treated	0.0003	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001
Copper	Raw	0.015	0.004	<0.001	0.165	<0.001	<0.001	0.015	0.054
	Treated	0.023	0.005	<0.001	0.576	<0.001	0.001	0.019	0.061
Lead	Raw	0.0008	<0.001	<0.001	0.022	<0.001	<0.001	<0.001	0.002
	Treated	0.0004	<0.001	<0.001	0.011	<0.001	<0.001	<0.001	0.001
Manganese	Raw	0.225	0.150	<0.001	2.120	0.007	0.050	0.303	0.552
	Treated	0.037	0.0035	<0.001	1.200	<0.001	<0.001	0.16	0.090
Mercury	Raw	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	Treated	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Molybdenum	Raw	0.005	0.003	<0.001	0.044	<0.001	0.001	0.007	0.012
	Treated	0.004	0.002	<0.001	0.048	<0.001	<0.001	0.007	0.011
Nickel	Raw	0.001	<0.001	<0.001	0.015	<0.001	<0.001	0.001	0.003
	Treated	0.0005	<0.001	<0.001	0.012	<0.001	<0.001	<0.001	0.002
Selenium	Raw	0.0002	<0.001	<0.001	0.005	<0.001	<0.001	<0.001	0.001
	Treated	0.0001	<0.001	<0.001	0.005	<0.001	<0.001	<0.001	<0.001
Silver	Raw	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	Treated	0.0001	<0.001	<0.001	0.011	<0.001	<0.001	<0.001	<0.001
Thallium	Raw	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	Treated	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Titanium	Raw	0.002	0.002	<0.001	0.015	0.001	0.002	0.002	0.003
	Treated	0.002	0.002	<0.001	0.008	<0.001	0.001	0.002	0.002
Vanadium	Raw	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	Treated	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Uranium	Raw	0.005	0.002	<0.001	0.059	<0.001	<0.001	0.006	0.014
	Treated	0.003	0.0005	<0.001	0.049	<0.001	<0.001	0.004	0.010
Zinc	Raw	0.361	0.019	0.001	12.27	0.002	0.006	0.113	0.669
	Treated	0.079	0.005	<0.0001	6.078	<0.0001	0.002	0.016	0.077

Table 10 Percentage of the Samples Compared to the Guideline Values

Parameter	**Guideline Value (mg/L)**	**% under Guideline Before /After Treatment**	**Guideline – Source/type**
Aluminum	0.1	99 / 100	HC- operation
Antimony	0.006	100 / 100	HC - health
Arsenic	0.01	52 / 71	HC - health
Barium	1.0	99 / 100	HC - health
Boron	5.0	100 / 100	HC - health
Cadmium	0.005	100 / 100	HC - health
Chromium	0.05	100 / 100	HC - health
Copper	≤ 1.0	100 / 100	HC - aesthetic-quality
Lead	0.01	97 / 99	HC - health
Manganese	≤ 0.05	25 / 85	HC - aesthetic-quality
Mercury	0.001	100 / 100	HC - health
Molybdenum	0.07	100 / 100	WHO - health
Nickel	0.07	100 / 100	WHO- health
Selenium	0.01	100 /100	HC - health
Uranium	0.02	95 / 98	HC - health
Zinc	≤ 5.0	98.6 / 99.2	HC - aesthetic-quality

HC = Guidelines for Canadian Drinking Water Quality (Health Canada 2008), WHO = World Health Organization Guidelines for Drinking-water Quality, 3rd edition (WHO 2008)

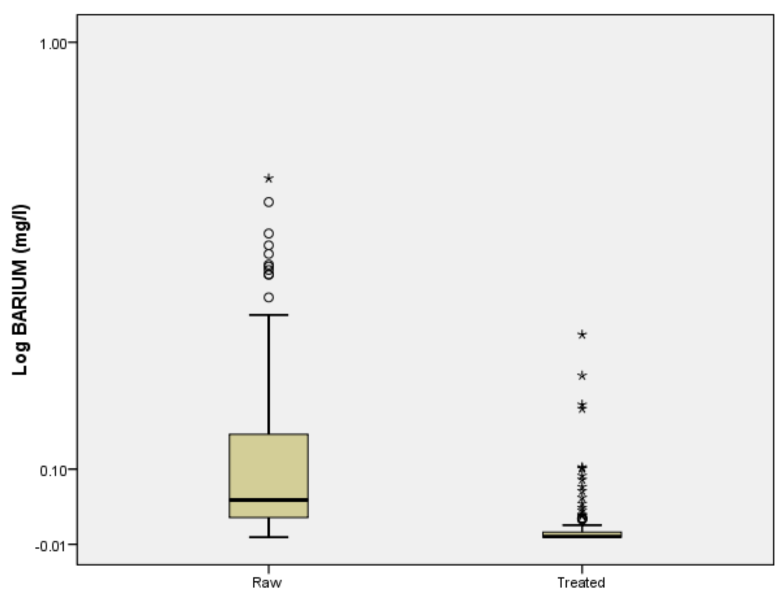


Figure 36 Distribution of Barium

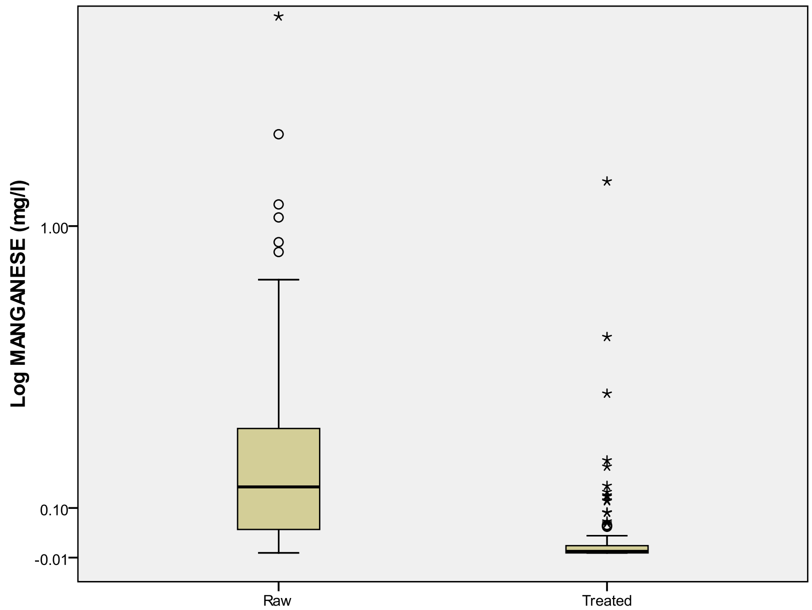


Figure 37 Distribution of Manganese

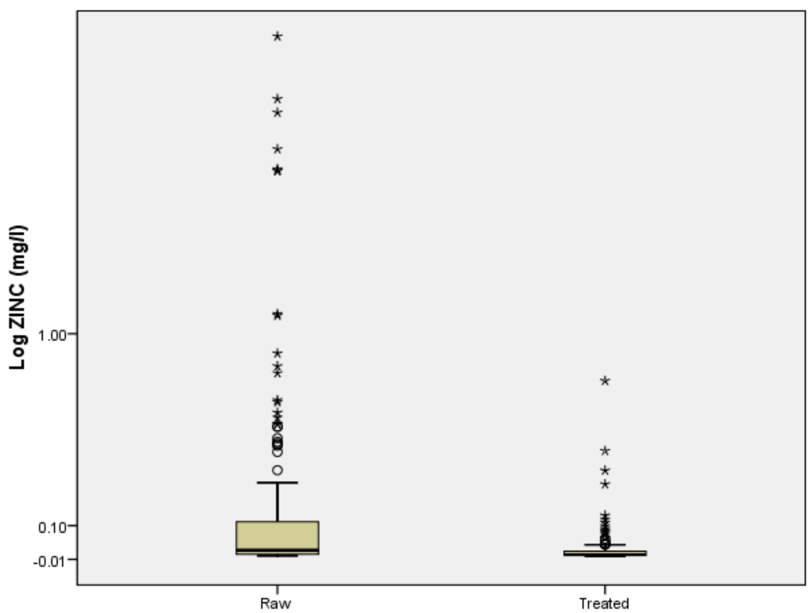


Figure 38 Distribution of Zinc

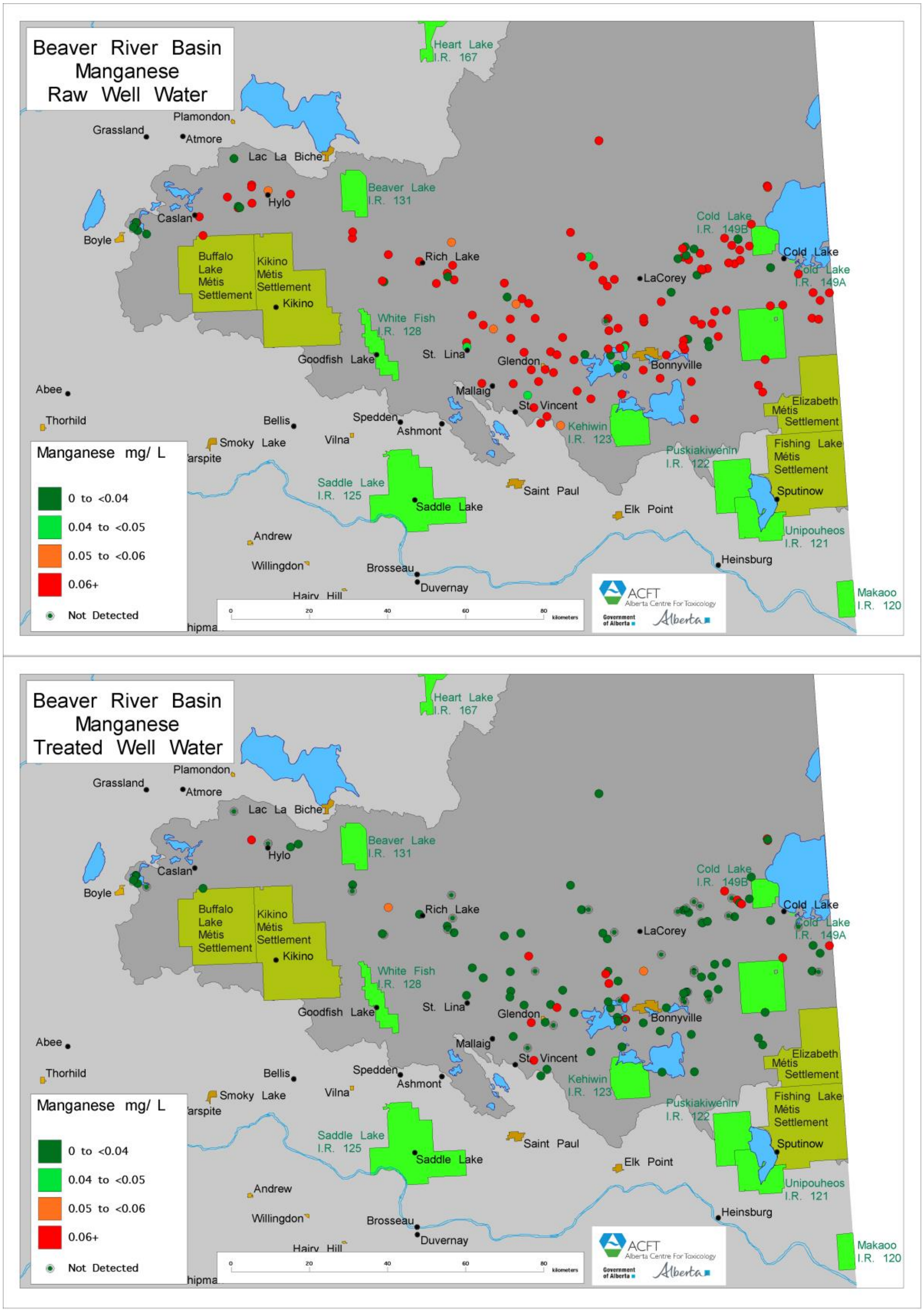


Figure 39 Spatial Patterns with Respect to Manganese Guideline before and after Treatment

3.5 Arsenic

- ✓ Arsenic levels were under the health-based guideline value in 52 per cent of raw water samples and 71 per cent of treated water samples
- ✓ Arsenic levels were not significantly different in raw water samples in the Beaver River Basin region between 1999 and 2009
- ✓ Arsenic levels were higher in raw water samples in the Beaver River Basin region than the average level of arsenic in Alberta
- ✓ The major species of arsenic found in the well water were inorganic arsenic III and arsenic V
- ✓ Arsenic levels were significantly reduced after water treatment
- ✓ Reverse osmosis and distillation efficiently removed arsenic from the raw water
- ✓ Iron filtration removed arsenic efficiently in most houses, but a small increase in arsenic occurred after treatment in a few households which may result from inappropriate maintenance of the iron filter
- ✓ 70 per cent of participants used raw or treated well water for human consumption
- ✓ 15 per cent of participants were exposed to arsenic at a level greater than the guideline value of 0.01 mg/L via drinking raw or treated water
- ✓ The daily intake of arsenic for these participants exposed to arsenic level over 0.01 mg/L in well water was 0.0007 mg/kg body weight per day
- ✓ An exposure ratio was 0.35 by comparing the tolerable daily inorganic arsenic intake of 0.002 mg/kg body weight per day as proposed by the World Health Organization
- ✓ Although the health risk resulting from drinking arsenic containing well water is estimated to be low, it is recommended that the private well owners should chose various methods to reduce arsenic exposure
- ✓ In order to more efficiently reduce exposure to arsenic via drinking well water, strategies should be set up for choosing treatment methods, appropriate maintenance for water treatment, alternative water sources or regular arsenic testing

3.5.1 Concentrations in Raw Water Samples

The mean and median of arsenic were 0.013 and 0.007 mg/L with a range of < 0.001 to 0.055 mg/L in raw water samples (Table 9). The Canadian guideline for arsenic is health-based at a level of 0.01 mg/L (Health Canada 2006). Arsenic levels were under the health-based guideline value in 52 per cent of raw water samples (Table 10). The percentage of under the guideline value in raw water samples in 2009 was similar to that in 2000. In 2000, arsenic levels were under the health-based guideline value in 50 per cent of raw water samples (AHW 2000).

A comparison of the mean and median of arsenic in raw domestic well water samples in the different years in the BRB region and the different locations of Alberta is listed in Table 11. The summary of the results are listed as

1. the mean levels of arsenic were not significantly different in raw water samples collected from the BRB region in 2009 and 1999-2000 ($p = 0.45$) (Figure 40);
2. the mean levels of arsenic were higher in raw water samples collected from the BRB region than the average level of arsenic of Alberta ($p <0.01$) (Figure 41);
3. the results from province-wide survey showed that localized high levels of arsenic were found in the Beaver River Basin region and some sites of central Alberta zone (red dots, Figure 42); and
4. the higher arsenic levels in groundwater were found in some areas of other provinces in Canada: the mean of 0.07 mg As/L in groundwater in Manitoba and 0.58 mg As/L in British Columbia (Wang and Mulligan 2006).

Table 11 Comparison of Arsenic levels in Raw Water Samples

Year	Location	Mean (mg/L)	Median (mg/L)	No. of Well Site
2009	Beaver River Basin	0.013	0.007	146
1999 - 2000	Beaver River Basin	0.013	0.008	59
2002 - 2008	Alberta	0.007	<0.001	249

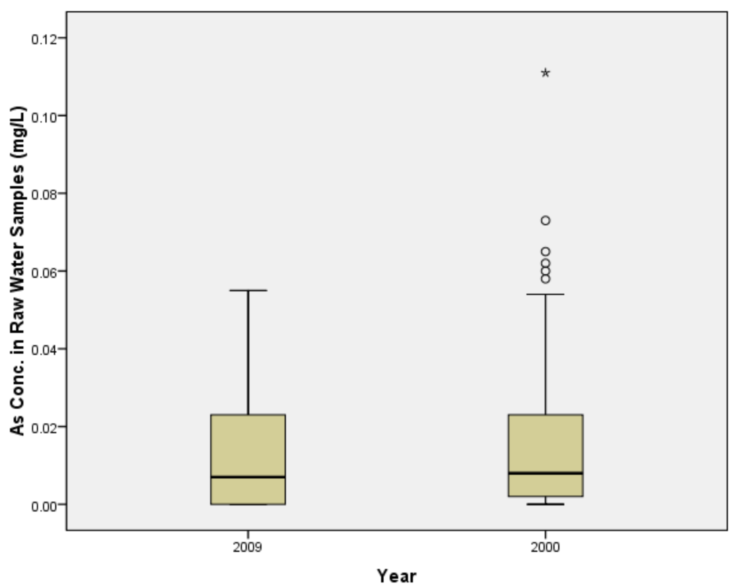


Figure 40 Distribution of Arsenic in Raw Water Samples in 2009 and 2000

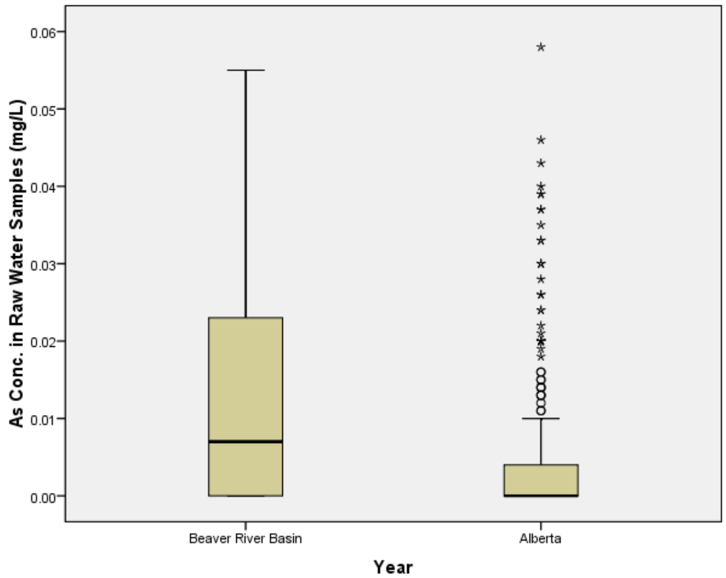


Figure 41 Distribution of Arsenic in Raw Water Samples in the BRB Region and Alberta

3.5.2 Concentrations in Treated Water Samples

The mean and median of arsenic were 0.008 and 0.002 mg/L, respectively, with a range of < 0.001 to 0.045 mg/L in treated water samples (Table 9). The mean levels of arsenic were significantly reduced after water treatment ($p < 0.01$) (Figure 43). The mean levels of arsenic were lower in treated water samples collected from the BRB region in 2009 and 1999-2000 ($p < 0.01$) (Figure 44). Arsenic levels were under the health-based guideline value in 71 per cent of treated water samples (Table 10 and Figure 45).

3.5.3 Concentrations of Arsenic Species

Arsenic occurs in organic and inorganic forms in the environment. Inorganic arsenic is the major form in natural groundwater. Arsenic specie commonly found in raw and treated water samples were arsenic III (arsenite, +3 valence) and arsenic V (arsenate, +5 valence).

The levels of arsenic III and arsenic V were summarized in Table 12. The summary of the results is listed as

Table 12 Summary of Arsenic Concentrations

Species	Raw Water Sample (mg/L)		Treated Water Sample (mg/L)		P Value
	median	mean	median	mean	
As III	0.005	0.0096	0.0003	0.0055	0.003
As V	0.0016	0.0036	0.0007	0.0025	0.116

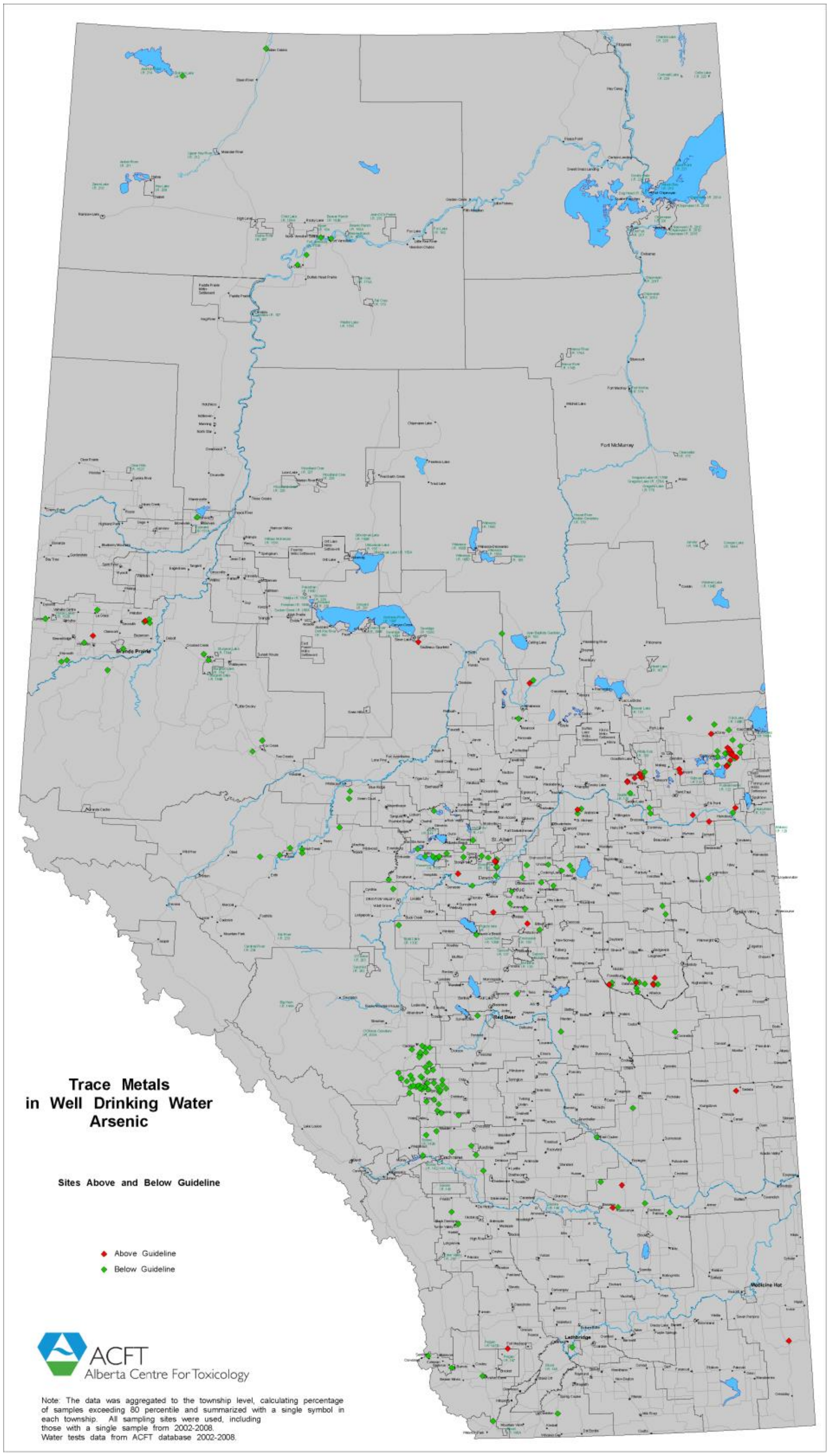


Figure 42 Spatial Pattern with respect to Arsenic Guideline in Alberta

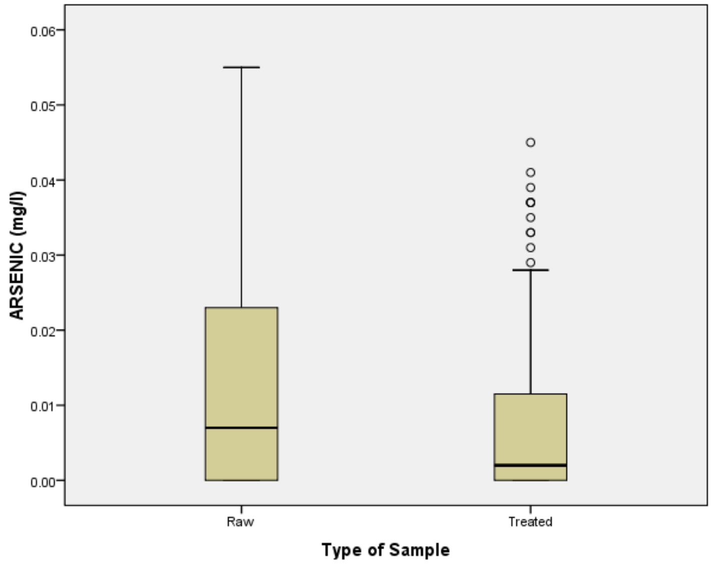


Figure 43 Distribution of Arsenic before and after Treatment

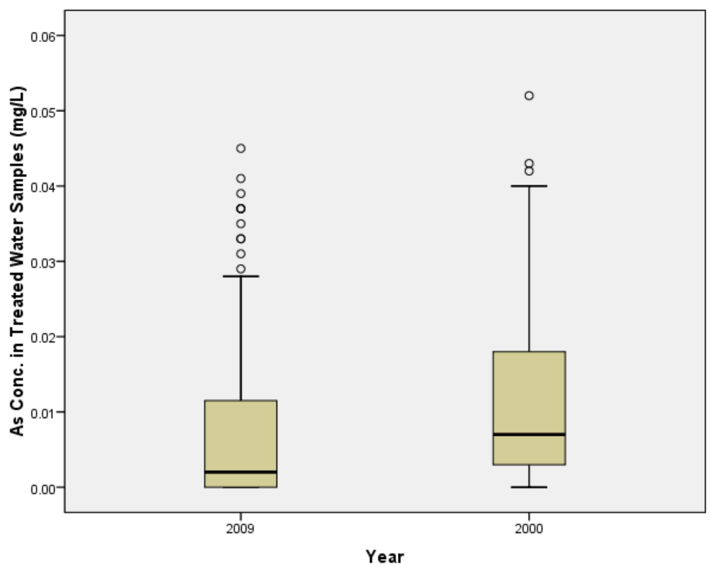
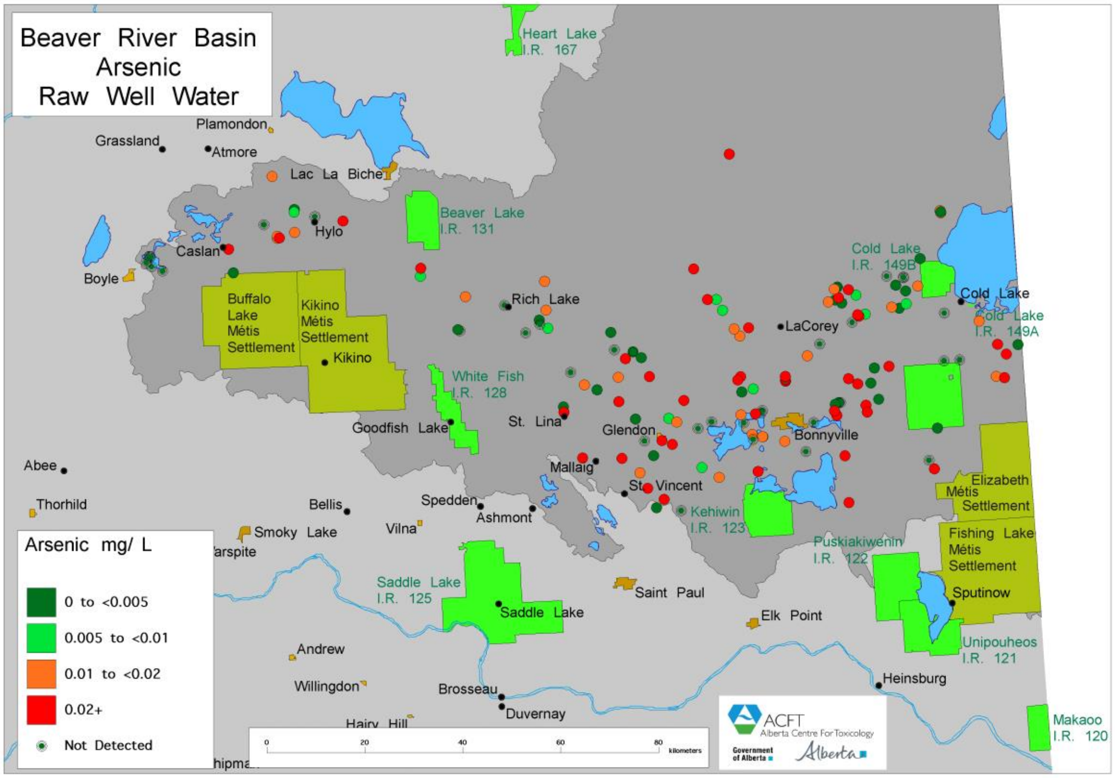


Figure 44 Distribution of Arsenic in Treated Water Samples in 2009 and 2000



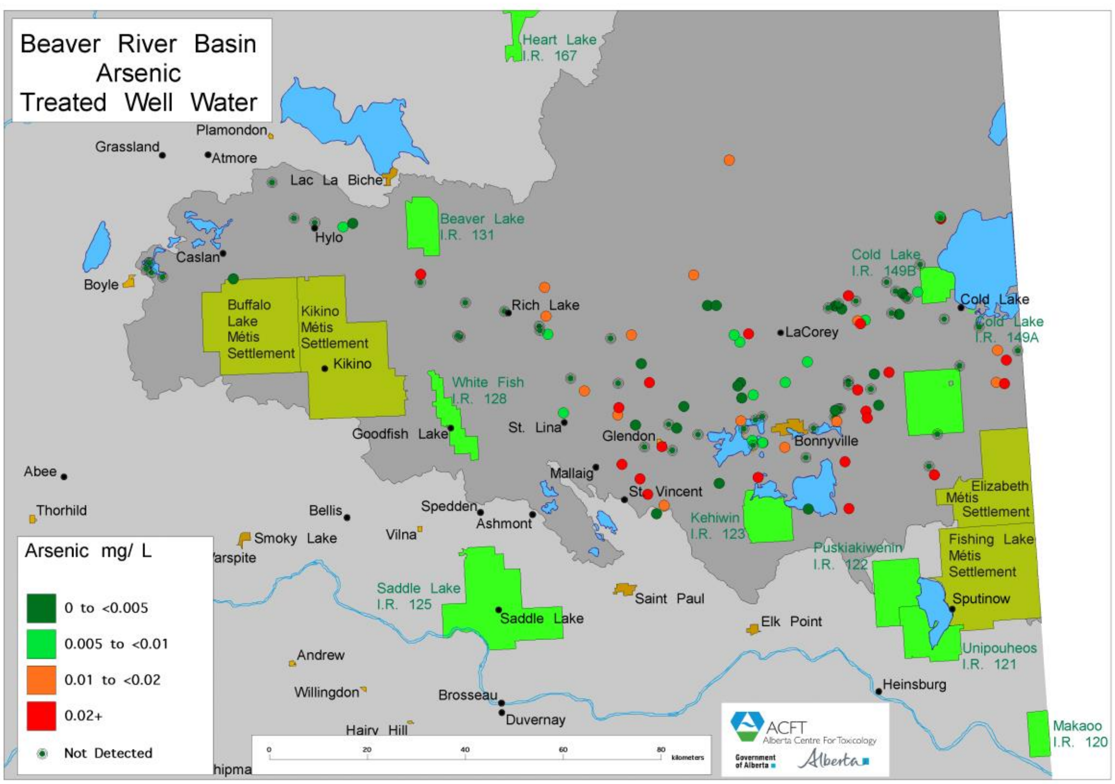


Figure 45 Spatial Patterns with Respect to Arsenic Guideline before and after Treatment

1. arsenic III levels were higher than arsenic V levels in raw water samples (Figure 46);
2. after water treatment, arsenic III levels were significantly reduced ($p < 0.01$) (Figure 46);
3. arsenic V levels were lower after water treatment, but not statistically significantly different ($p = 0.116$) (Figure 46);
4. arsenic specie levels varied from one well to another, even within a very small area of the province like the BRB region;
5. reverse osmosis and distiller efficiently removed As III and As V (Table E of Appendix D); and
6. arsenic V concentrations was slightly increased after using iron filtration in some households (Table E of Appendix D).

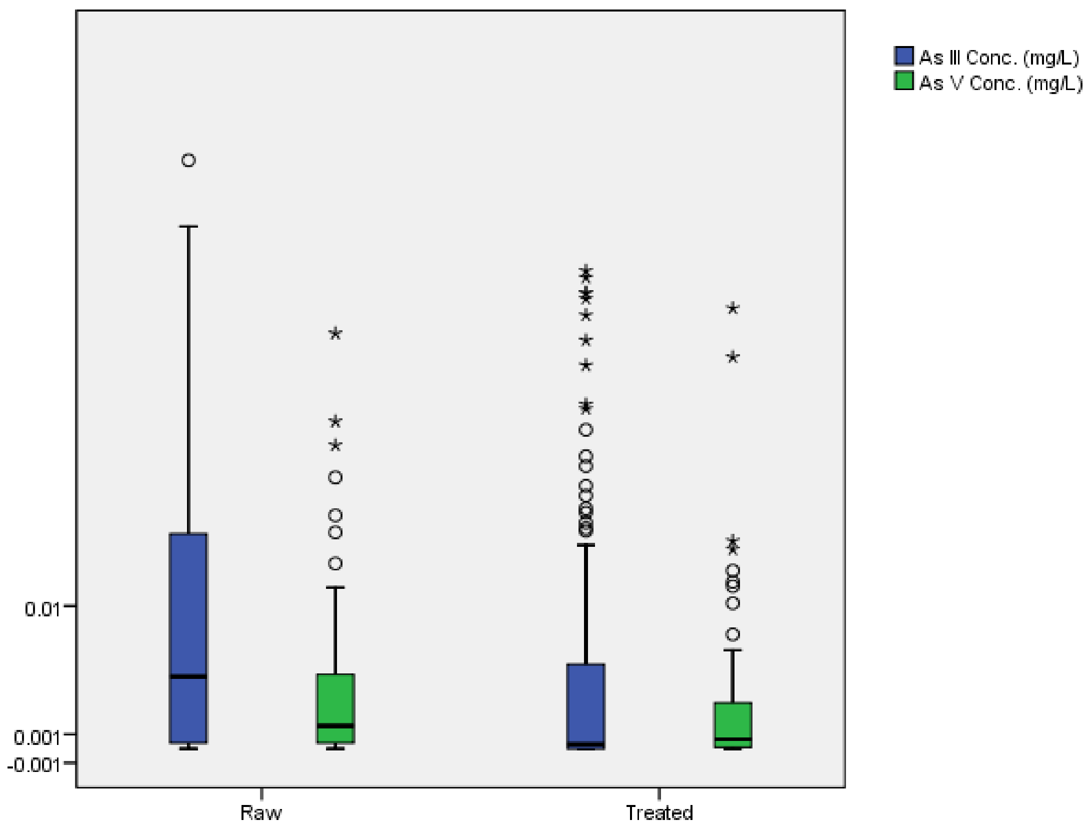


Figure 46 As III Levels before and after Treatment

Although the percentage increase of arsenic V levels in some cases seemed to be high after using iron filtration method, the absolute arsenic V concentration increases were small (0.001-0.003 mg/L). Some of these small increases in arsenic V could have been due to oxidation and release of the arsenic captured on the iron filters. This suggests that iron filters need to be replaced regularly. If the filter has been used for a long time and is saturated with arsenic and other ions, the previously adsorbed arsenic can be released, resulting in increased concentration.

The information about the arsenic species in the water can be helpful when considering the treatment needed. Arsenic V is much easily removed as compared to arsenic III (USEPA 2001). Using a pre-oxidation method such as chlorination will convert arsenic III to arsenic V in the water and increase efficiency for arsenic removal. Various treatment methods are described in a fact sheet provided in Appendix E.

3.5.4 Water Consumption and Use Patterns

A total of 152 participants provided the information on the well water consumption and well water use pattern. The information is summarized in Table 13. The summary of the result is listed as

1. 70 per cent participants only consumed cold tap water from the kitchen tap;
2. 7 per cent participants consumed cold plus hot tap water from the kitchen tap;
3. 32 per cent participants consumed cold tap water from the kitchen tap plus cold bottled water;
4. an average volume of total fluid consumption (tap water, bottled water, beverages, soup etc.) was 3.16 L per day;
5. an average volume of water consumption was 1.97 L per day for tap water from the kitchen tap and 1.86 L per day for bottled water.;
6. 70 per cent of participants used tap water for drinking;
7. 95 per cent of participants used tap water for cooking;
8. 96 per cent of participants used tap water for washing food;
9. 70 per cent of participants used tap water for making beverages;
10. 95 per cent of participants used tap water for brushing teeth; and
11. 93 per cent of participants used the water in house for laundry and bathing/showering.

3.5.5 Daily Arsenic Intake from Drinking Tap Water

The exposure information is summarized in Table 14. Among 152 participants, 32 (21 per cent) of them used raw tap water from their kitchen tap for various purposes.

Of these 32 houses, arsenic levels greater than 0.01 mg/L were found in nine wells. Out of these nine participants, five of them used bottled water for drinking. Four of them directly consumed raw tap water containing arsenic levels ranging from 0.013 to 0.032 mg/L (Table 15).

Table 13 Well Water Consumption and Use Patterns

Type of Water Consumed	No. of Participant	Percentage (%)
Cold water from kitchen tap only	106	70
Cold + boiled water from kitchen tap	10	7
Boiled water from kitchen tap only	4	3
Cold tap water + cold bottled water	48	32
Bottled water only	42	28
Water not from participant wells (e.g. workplace)	13	9
Volume of Water Consumption	**L/d**	
Total fluid consumption	3.16	
Tap water	1.97	
Bottled water	1.86	
Coffee	0.94	
Tea	0.65	
Juice	0.64	
Soup	0.26	
Use of Water	**No. of Participant**	**Percentage (%)**
Drinking	106	70
Cooking	145	95
Washing food	146	96
Using tap water to make beverage	107	70
Brushing teeth	144	95
Laundry	142	93
Bathing/showering	145	93

Table 14 Exposure Patterns – Consumption of Raw and Treated Water

	No.
Raw Water	
Total number of households using raw tap water for various uses	32
Number of well with As levels > 0.01 mg/L	9
Number of participants who consumed raw water with As > 0.01 mg/L	4
Number of participants who did not consume raw water with As > 0.01 mg/L and consumed bottled water only	5
Treated Water	
Total number of households using treated tap water for various uses	120
Number of well with As levels > 0.01 mg/L after treatment	22
Number of participants who consumed treated water with As > 0.01 mg/L	19
Number of participants who did not consume treated water with As > 0.01 mg/L and consumed bottled water only	3

Table 15 Exposure Patterns and Treatment Methods

	As_Raw mg/L	**As_Treated** mg/L	**Water Consumption** L/d	**As Intake** mg/d	**Treatment Method**
Raw Water					
1	0.013	-	2	0.026	no
2	0.025	-	1.3	0.033	no
3	0.014	-	1.0	0.014	no
4	0.032	-	1.3	0.042	no
mean	**0.021**		**1.4**	**0.029**	
Treated Water					
1	0.027	0.028	2.0	0.056	softener, iron filter
2	0.016	0.021	2.5	0.052	softener, iron filter
3	0.024	0.020	4.5	0.090	softener
4	0.025	0.019	2.0	0.038	softener
5	0.040	0.033	3.0	0.099	softener
6	0.029	0.028	2.0	0.056	softener
7	0.012	0.011	1.0	0.011	softener
8	0.037	0.037	2.0	0.074	softener
9	n/a	0.018	2.5	0.045	softener
10	0.042	0.024	1.5	0.036	softener, iron filter, RO
11	0.018	0.017	1.3	0.022	softener
12	0.038	0.037	3.0	0.111	softener
13	0.041	0.017	2.0	0.034	softener
14	0.038	0.041	1.0	0.041	softener
15	0.019	0.017	1.0	0.017	softener
16	0.028	0.020	1.0	0.020	softener
17	0.010	0.011	2.0	0.022	softener
18	0.047	0.029	2.0	0.058	softener
19	n/a	0.011	1.0	0.011	softener
mean	**0.029**	**0.023**	**1.96**	**0.047**	

Well water was treated by various methods in 120 households. Arsenic levels greater than 0.01 mg/L were found in 22 out of 120 households. Out of these 22 participants, three of them used bottled water for drinking. 19 of them directly consumed treated tap water every day. The arsenic levels ranged from 0.011 to 0.041 mg/L in the treated water samples (Table 15).

Daily total arsenic intake from drinking well water is not only dependent on arsenic levels in the water but also on the volume of water consumed. The amount of arsenic intake in these 19 participants varied from 0.011 to 0.111 mg per day. The more water consumed per day such as for Case #3 and #12, the greater arsenic amount intake.

Treatment methods and exposure patterns are shown for houses having arsenic level greater than 0.01 mg/L in the treated water samples in Table 15. In 16 households, a softener was the only type of water treatment. Softeners did not reduce arsenic levels efficiently in the water. In two houses in which iron filtration was added for water treatment (Case #1 and #2), arsenic levels slightly increased. In one house (Case #10) in which reverse osmosis was used, arsenic levels were reduced from 0.042 mg/L to 0.024 mg/L.

It is important for well owners to recognize that the use of softeners does not reduce arsenic levels in raw water efficiently, and they cannot be relied upon to reduce arsenic to less than the guideline level of 0.01 mg/L. Use of efficient treatment methods or use of alternative water sources for human consumption are some means for reducing exposure to arsenic from drinking water.

3.5.6 Exposure Assessment

Out of 152 participants, a total of 23 (15 per cent) participants were exposed to arsenic greater than the guideline level of 0.01 mg/L by drinking raw or treated tap water. The average daily arsenic intake amounts were

1. 0.029 mg per day for three participants who consumed raw tap water; and
2. 0.047 mg per day for 19 participants who consumed treated tap water.

If using 65 kg body weight for an adult, the daily arsenic intake is 0.0007 mg/kg body weight per day.

People are exposed to arsenic via many sources. Canadians are mainly exposed to arsenic via ingestion of food such as meats, vegetables and seafood (Health Canada 2006). The form of arsenic in food is mainly organic arsenic which is less toxic than inorganic arsenic. The estimated arsenic intake from food is 0.042 mg per day, with a range of 0.022 – 0.079 mg per day for Canadian adults. About 0.01 mg per day of arsenic intake from food is inorganic arsenic. On average for Canadians less than 0.0075 mg per day of inorganic arsenic comes from drinking water. Thus, these 19 participants in the BRB region consumed more inorganic arsenic (0.047 mg per day) than an average level of arsenic intake (0.0075 mg per day) in Canadian adults.

Whether or not such exposure levels of inorganic arsenic cause short-term and long-term adverse health effects depends on many factors. Most common factors are diet, genetic make-up, lifestyle and current health conditions. Arsenic is known to increase the development of some health problems and is accepted as causing cancer in humans at high levels of exposure. The evidence for adverse human health outcomes is based on a number of situations of high human exposure to arsenic via drinking water around the world. Chakraborti et al. (2002) estimate that 31 million people are exposed to more than 0.05 mg/L arsenic in the drinking water in the Bengal delta of India and Bengladesh. Castro de Esparza (2009) estimates that 4.5 million people are exposed to more than 0.05 mg/L in Latin America (mainly Chile and Argentina). Influential epidemiology studies about arsenic in drinking water causing cancer were performed in Taiwan where drinking water levels have been reported from 0.35 to 1.1 mg/L (Chen and Wu 1962, Chen et al. 1985).

How likely people are to experience adverse health outcomes from exposure to arsenic in well water depends on:

1. amount of arsenic in domestic well water,
2. volume of tap water consumed by people every day,
3. duration of exposure (this arsenic guideline level is based on drinking arsenic-containing water for 70 years), and
4. sensitivity of an individual to arsenic.

However, more exposure to arsenic increases the chance that health problems may occur. Reducing exposure to arsenic reduces the risk for potential health problems.

3.5.7 Human Health Risk

Arsenic is thought to be essential in trace amounts, but the benefits are little known. It is used in homeopathic treatments for some digestive problems including burning pain and symptoms of dehydration and at high dose for cancer treatment like acute promyelocytic leukemia. Most people receive sufficient arsenic from their diet to satisfy any likely trace element requirements.

Exposure to arsenic in drinking water may pose a health risk, depending on the exposure amount. Swallowing a large amount of inorganic arsenic from food or water (above 1.5 mg per kilogram of body weight or approximately 1.5 L of water at an enormous concentration of 70 mg/L) can cause death, but this would be considered poisoning, not incidental arsenic consumption (ATSDR 2007).

The studies found that people exposed to arsenic from groundwater at a level greater than 0.05 mg/L over six months experienced skin lesions, non-pitting edema, respiratory diseases, gastro-intestinal, liver, and cardio-vascular problems in humans (Bates et al. 1992, Hopenhaqvn-Rich et al. 2000, NRC 2001, Vather and Concha 2001, Tchounwou et al. 2003, Kapai et al. 2006, Naidu 2009). These adverse chronic health effects have been found at an exposure level greater than 0.01 mg As/kg body weight per day by people who consumed arsenic-containing water based on human epidemiological studies in the world (Tchounwou et al. 2004).

Some studies indicate increased risk of tumors of the skin, liver, bladder and lung resulting from long term, exposure to arsenic at relatively high levels in water. A few studies found no harmful health effects in persons in the United States who drank water containing arsenic at levels of 0.05 to 0.1 mg/L throughout their life time (ATSDR 2007).

Scientists continue to investigate the long term health effects caused by exposure to levels of arsenic less than 0.05 mg/L. Some investigators evaluated cancer potency indices in internal organ cancers such as the liver, lung, bladder, and kidney caused by ingesting inorganic arsenic in drinking water. The greatest lifetime risks for development of lung and bladder cancers were estimated at an exposure level of 0.01 mg As/kg body weight per day (Chen et al. 1992).

Based on the available information, Health Canada revised the Canadian Drinking Water Quality guideline for arsenic in 2006. The new guideline level is 0.01 mg/L. Health Canada chose to use the Taiwan epidemiologic evidence for the incidence of internal (lung, bladder, liver) with a Poisson model recommended by the U.S. EPA (2001a) and fit by Morales *et al.* (2000) with an external unexposed comparison population for estimating the cancer risks associated with the ingestion of arsenic in drinking water. On this basis, the estimated lifetime cancer risk associated with ingestion of water containing arsenic at 0.01 mg/L (10 µg/L) is from 3.0×10^{-5} to 3.9×10^{-4} (Health Canada 2006). Some later studies in the United States (Steinmaus et al. 2003, Lamm et al. 2004, U.S. EPA and AwwaRF 2004,) found no clear association between lung and bladder cancer risks and arsenic levels in drinking water between 0.01 and 0.05 mg/L, but Health Canada found the smaller sample size and some methodological weaknesses with the U.S. studies provided sufficient justification to choose the Taiwan evidence as the appropriate, cautious approach for developing an arsenic guideline. This was also the approach chosen by the U.S. EPA in developing their new and equivalent drinking water standard of 0.010 mg/L for arsenic.

The Health Canada approach for choosing the evidence to judge the guideline value was cautious. The value of 0.010 mg/L poses a higher cancer risk than Health Canada normally chooses as a negligible risk. The higher number was chosen because available treatment technologies cannot achieve a level of 0.0003 mg/L that would correspond to a truly negligible lifetime cancer risk. There is continuing research to understand by what mechanism arsenic in drinking water causes human cancers because there may be factors involved, such as nutrition and non-genotoxic[2] mechanisms

The rural population in the BRB region is about 15,000. If 15 per cent private well owners consume the water with arsenic greater than 0.01 mg/L, the region could have 2,250 people at risk. Assuming the highest cancer risk value estimated by Health Canada would require more than 70 years to have a single case of cancer occur from drinking well water at 0.010 mg/L for those 70 years. Such a low level of cancer risk is hypothetical and is far too low to detect by population health

[2] Genotoxic with reference to carcinogens refers to the ability of a carcinogen to damage DNA or otherwise interfere with cell replication at the genetic level such that it is a viable hypothesis that there may be no level of exposure below which the risk of cancer is zero. Genotoxic carcinogens are treated as a matter of cautious public health policy as if they have no threshold and the resulting calculations for allowable exposures (e.g. as a drinking water guideline) are very low. There is some possibility that arsenic causes cancer by a non-genotoxic mechanism and, if so, there may be zero risk of cancer below some threshold value. The epidemiologic studies on the U.S. at lower levels of arsenic exposure (0.010 to 0.050 mg/L) than exist in Taiwan (>>.0.05 mg/L) cannot currently prove or disprove this possibility.

surveillance. For comparison, the lifetime risk of being diagnosed with cancer for all Canadian males is 45% and for all Canadian females is almost 40%.

A comparison of risk from various causes is summarized in Table 16. If comparing to a health risk resulting from tobacco smoking, the risk from drinking arsenic containing water is estimated to be 225 time less that that from smoking.

Table 16 Comparison of Risk from Various Causes

Cause	Voluntary (V) / Involuntary (I)	Lifetime risk of premature death (per 100,000)
Smoking (all cancers)*	V	21,900
Smoking (cancer only)*	V	8,800
Motor vehicle	I	1,600
Frequent airline passenger	V/I	730
Coal mining accidents	I/V	441
Indoor radon*	V/I	400
Motor vehicle – pedestrian	I	290
Environmental tobacco smoke/living with a smoker*	I/V	200
Diagnostic X-rays*	I	75
Cycling deaths	I/V	75
Lighting strike	I	7
*Max estimate for skin cancer by drinking As-containing water at 0.01 mg/L**	*I*	*3***
Hurricanes	I	3

Source: Darnay (1992) * indirect risk estimates - more uncertain than risks where the cause of death is not in doubt , e.g. motor vehicle fatalities (Thomas and Hrudey 1998). Of these indirect risks, the smoker's risk estimates are the most certain because of the large population base and extensive research to establish the link between smoking and various causes of death. ** based on 14% fatal rate of skin cancer at a risk level of 9×10^4

3.5.8 Controlling Risks

Although a health risk resulting from exposure to arsenic from drinking well water is low, it is recommended to the private well owners to consider various methods to reduce their exposure to arsenic.

66 per cent of wells were tested for chemical parameters before this survey. Although arsenic levels were not significantly changed with years, it is recommended to have the well being testing regularly, particularly for the well water containing arsenic level greater than 0.01 mg/L. Regular testing will provide the information to the well owners whether or not they should select any options to reduce a potential health risk resulting from exposure to arsenic from drinking well water.

One of options is to use household water treatment methods to remove or reduce arsenic levels in drinking water. Reverse osmosis and distiller remove arsenic efficiently. Iron filter can remove arsenic if the owners maintain these devices appropriately.

The use of alternative drinking water sources is another option if arsenic level was over 0.01 mg/L and appropriate treatment methods are not used in household.

3.6 Reported Water Quality Issues and Well Maintenance

Questionnaires on reported well water quality issues and well maintenance were performed for each participant. The results are summarized in Table 17. 71 per cent owners complained the well water quality issues in terms of colour, smell and taste. 34 per cent owners smelled sulfur odour. 54 per cent owners used shock chlorination. An average distance from wells to septic tanks, animal pens and fertilizer storages were over 60 meters. In some cases these distances were substantially smaller (i.e. only 8 to 20 m) and depending on the surficial geology, such wells may be at significant risk from surface contamination. In any case, the well bore and well head must always be protected from the ingress of surface water.

Table 17 Reported Well Water Quality Issues

Question	Yes # participant	% of participant	Description
Do you have any well water quality issues?	108	71	Colour – yellow, rusty, black Odour – sulfur, gasey Taste – metallic Hardness – too hard
Is there a sulfur odor from the water?	51	34	
Is there greasy slime growth on the toilet flush tank?	30	20	
Have you noticed a decrease in well yield?	19	13	
Has there been recent flooding or high water around the well?	6	4	
Was the well shock chlorinated?	81	54	
At what depth is your pump set?	104	63	Mean = 28 m Range = 4.5 – 82 m
Distance from septic tank/field/ discharge	143	95	Mean = 99 m Range = 20 – 450 m
Distance from fuel storage	54	36	Mean = 110 m Range = 20 – 500 m
Distance from manure storage	17	11	Mean = 180 m Range = 20 – 500 m
Distance from fertilizer storage	6	4	Mean = 60 m Range = 30 – 600 m
Distance from animal pens	59	49	Mean = 84 m Range = 8 – 500 m

4. CONCLUSIONS

The major findings are summarized below:

Untreated domestic well water

1. suitability of domestic water quality for human use by measuring pH, alkalinity, conductivity and TDS was similar in the Beaver River Basin region to suitability in other regions of Alberta;
2. aesthetic water quality by measuring iron, chloride and sulfate was slightly under average level in Alberta;
3. well water was very hard in the Beaver River Basin region compared to water classified as "medium hard or hard" in Alberta;
4. the average sodium level was lower than average levels in other regions of Alberta; and
5. the levels of fluoride, nitrate/nitrite, antimony, barium, boron, cadmium, chromium, lead, mercury, molybdenum, nickel, selenium, and uranium were under the health-based guidelines for 95 to 100 per cent of raw water samples.

Treated domestic well water

1. treatment methods included using softeners, iron filters, reverse osmosis, distillers, activated carbon filters, and chlorinators;
2. alkalinity, conductivity, TDS and bicarbonate were significantly removed by using a combination of treatment methods;
3. hardness was significantly reduced after water treatment, and very hard water became soft water in 80 per cent of houses after using softeners; and
4. sodium or potassium levels were significantly increased after using softeners in some houses, depending on the type of softening chemicals used.

Special issue: arsenic

1. arsenic levels satisfied the health guideline value in 52 per cent of raw water samples and 71 per cent of treated water samples;
2. arsenic levels did not significantly change between 1999 and 2009;
3. arsenic levels were higher in the region than the average level in Alberta;
4. the major arsenic species in well water were inorganic arsenic III and V;
5. arsenic levels were significantly reduced after water treatment, particularly by using reverse osmosis and distiller;
6. 15 per cent of participants consumed water containing arsenic level greater than the health guideline level of 0.01 mg/L; and

7. a daily intake of arsenic from drinking well water for 19 participants who consumed water with arsenic level greater than 0.01 mg/L was averaged 0.0007 mg/kg body weight per day.

Human health assessment

1. 79 per cent of participants treated domestic well water for household use such as using for daily drinking (70 per cent) and for cooking, food preparation, bathing/showering and laundry (over 90 per cent);
2. there may be an increase of potential health risk for cardiovascular health effects if private well owners consume soft water containing very low levels of calcium and magnesium, or very high levels of sodium and potassium resulting from using softeners for a long time; and
3. potential health risk resulting from drinking arsenic-containing water at current measured levels was estimated to be low.

5. RECOMMENDATIONS

The findings suggest recommendations to:

1. private well owners should be advised to test the well water quality regularly, particularly if the arsenic levels exceed the Canadian Drinking Water Quality guideline or sodium and potassium levels are too high;
2. private well owners should be encouraged to select efficient treatment methods or choose alternative drinking water sources to minimize exposure to arsenic via drinking well water as much as possible even though health risk resulting from drinking arsenic containing water was estimated to be low;
3. private well owners should be encouraged to have appropriate maintenance of treatment devices to efficiently reduce the levels of chemicals including arsenic to satisfy the guideline values;
4. private well owners should be advised to avoid drinking soft water for a long term by using softeners appropriately (i.e. for non-consumptive uses only) for example by installing a water pipe to bypass the kitchen tap water;
5. private well owners should be advised how to access local public health officers to discuss well water quality, testing schedule, testing results, treatment methods, well maintenance and health concerns since they manage the well water quality by themselves;
6. public awareness of improving the well water quality should be enhanced;
7. various technical supports for private well owners should be provided by the experts in the fields of agricultural field engineering, public health inspection, and groundwater hydrochemistry.

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APPENDIX A

Questionnaires and Information Sheet, Consent Form

Domestic Well Water Quality Survey in Beaver River Basin Area
2009

Why is the Government of Alberta conducting a well water survey in the Beaver River Basin?

Some residents living in the Beaver River Basin have expressed concerns about the chemical quality of their domestic well water which is used as drinking water for their families. There is particular interest in both arsenic and uranium.

The survey will complement information collected in an earlier survey of arsenic in the Cold Lake area of the province in 2000, but it will also increase the number of wells tested, and expand testing to include routine chemicals and trace elements.

Funding for the survey is being provided through the Alberta *Water for Life Strategy* which supports the objective 'safe drinking water for all Albertans'.

What is the purpose of the survey?

Alberta Health and Wellness is working closely with Alberta Environment, Alberta Agriculture and Rural Development and the Beaver River Watershed Alliance to conduct a survey of domestic well water quality in the summer and fall of 2009 in the Beaver River Basin area..

The goals of the survey are:

To monitor domestic well water quality and establish baselines of domestic well water quality over time by:

- testing 21 routine chemicals as well as physical parameters
- testing 23 trace elements referenced in the *Canadian Drinking Water Guidelines*
- further analyzing the concentration of total arsenic and arsenic +3 (arsenite) and +5 (arsenate) which are associated with health concerns.

To assess exposure to routine chemicals and trace elements in domestic drinking well water by:

- asking questions about the amount of domestic well water used for drinking every day,
- asking questions about how domestic well water is used for non-drinking activities.

To provide public health advice and to help each well owner make an informed decision on how to improve the domestic well water quality by:

- providing information about the concentration of routine chemicals and trace elements in the drinking water before and after treatment, and providing information on water treatment options,
- providing information on the effectiveness of existing treatment systems in removal of arsenic (arsenic +3 and arsenic +5),
- providing a guide booklet to well owners whose results exceed the Canadian Drinking Water Quality Guidelines in order to help the well owner interpret the results, understand each of the tested chemicals and choose the best option for reducing exposure to these chemicals.

Who can participate?

A survey technician will visit up to 200 domestic wells in the Beaver River Basin area. Of the 200, 100 well owners from either the earlier survey in 2000 or who have had their wells tested previously through the Centre for Toxicology will be contacted to ask if they are willing to participate.

The remaining 100 wells have not yet been identified. Anyone living in the Beaver River Basin is invited to contact either Alberta Health and Wellness or the Beaver River Watershed Alliance office to request information on their participation. (For contact information, please refer to the last question).

What will be done in the 2009 survey?

The survey will include:

- testing for routine chemicals and trace elements including arsenic at each domestic well,
- further testing of the water for total arsenic and two types of arsenic known as arsenic +3 and arsenic +5.
- testing for physical parameters of the well water such as pH, conductivity etc.
- examining the well and its location, and
- completing a short questionnaire on water consumption and water treatment.

What are the benefits of participating?

Overall, the information generated from this survey will be used to better understand the risk, if any, posed by the water. The survey will provide information on well water quality, the influence of well maintenance, well water treatment efficiency and potential exposure levels to routine chemicals and trace elements via drinking of well water.

This information and the guide booklet will enable well owners to make the best decisions on how to improve well water quality, how to reduce exposure to unwanted chemicals and how to select proper treatment technology.

Who can you contact about the survey?

If you are interested in participating or have questions about the survey, please contact Alberta Health and Wellness, Surveillance and Assessment Branch at 780-427-4518 (Rite line 310-0000) or the Beaver River Watershed Alliance office at 780- 635-4920.

Participant ID____________ Interview Date______________ Phone#____________

Initial Telephone Questionnaire

For Previous Wells

Hello, ___________________, my name is __________. I am calling you on behalf of Alberta Health and Wellness. <*pause*> You may recall that we surveyed arsenic levels in groundwater in the Cold Lake area in 2000. We would like to check arsenic levels in your well water again after ten years to see if there are any changes in the levels. We would also like to test for other chemicals like uranium and check your overall well maintenance and protection. This will help us assess your exposure to some chemicals in your drinking water.

Do you use your well water for drinking every day?

- [No] I do not drinking water from my well water. → Thank you for your time.

Note: People will ask about why not include them. The response should be that this study is set up for human exposure assessment and the well owners who drink well water will be invited.

[Yes]

Are you interested in participating in this survey again?

- [No] I am not interested in participating → Thank you for your time.

For New Wells

Hello, ___________________, my name is __________. I am calling you on behalf of Alberta Health and Wellness. <*pause*> Alberta Health and Wellness is doing a survey to check private well water quality in the Beaver River Watershed. This will involve testing your water for chemicals, like arsenic and uranium; plus check your overall well maintenance and protection. This will help us assess your exposure to some chemicals in your drinking water.

Do you use your well water for drinking every day?

[No] → Thank you for your time

[Yes]

Are you interested in participating in this survey?

- [No] I am not interested in this study → Thank you for your time.

- [Yes], do you have about 10 minutes to discuss the project with me?
    - [No], this is not a convenient time
        - When is a better time to contact you?
        - Thanks, I will call you back at ____________________
    - [Yes], I have time to discuss the project with you.

Note: People will ask about cost. The response should be there is no cost to participate except their time and samples of water.

I would like to explain what we are planning to do. This survey will involve me visiting your home to:

- Take water samples from your well;
- Understanding what water treatment you use;
- Understand how you maintain your well; and
- Record the amount of water you drink from your well.

Any information collected from you, including this interview, will be held in strict confidence. While all participants will be asked the same questions and have the similar water samples taken; you will only get test results for your well. All results will be summarized into groupings/clusters for publication; no information about any individual person or well will be released to the public without consent of the individual. Information about your test results and legal land description may be provided to Alberta Environment, however it will not include any of your personal information.

If any of your results exceed the *Canadian Drinking Water Guidelines*, we will indicate this to you. You will also receive a guide booklet to help you understand your results. This guidebook will also provide you with additional information on how to protect your well and options for treatment. We hope that this information will aid you in determining how to improve the quality of your drinking water.

Note: At this stage, we are deliberately using the term quality as we do not know about the safety of their water. We do not want to cause unnecessary alarm.

Do you have any questions about this survey? → Answer any questions as needed; if you do not know the answer, indicate that you will check with the project manager and find that information for them

Are you still willing to participate in this survey?

- [No], I am not interested in participating in this survey. → Thank you for your time.

When is a good time to visit your home?

Date: ____________________________

Time: ____________________________

Thank you, may I confirm your name, address and contact phone number?

Name: ____

Mailing Address: ____

Detailed location & directions:

Home Phone #:

Is there an alternative number to contact you at? _________________________________

Comments:

____

When I visit your home, it would be helpful if you could have the following information available:

- Any previous laboratory results about your well water
- Driller's report and/or well depth
- Well ID – this may be found on the well if you do not have a paper record
- Legal land description
- Treatment information

Also, please think about how much water you drink from your well. This includes amounts used to make coffee, tea or juice.

Note: We have asked them to collect a lot of information and to think about their water consumption. However if you are having a good dialogue with the participant, elaborate by asking them to think about their total fluid consumption and bottled water usage.

If you know other people are interested in this survey, please ask them to contact me at______________________.

Thank you very much for your time, if you have any change and questions, please give me a call.

INFORMATION SHEET

Domestic Well Water Quality Monitoring and Human Health Risk Assessment in the Beaver River Basin Region

Purpose	This survey is to: • monitor domestic well water quality and establish geographical location and chemical levels over time in the Beaver River Basin region, • assess exposure to selected human health related chemical, contaminants though drinking domestic well water, and • Provide you with information about the quality and safety of your well water.
How will this survey be conducted?	Trained personnel will visit you at your home to: • Complete with you a short survey on when and how you use your well water; • Sample water from your well. The number of samples taken will be dependent on the type of treatment you use. It is expected that six (6) to twelve (12) samples may be taken and • Visibly inspect your well to see if it is secure and what may be influencing the quality or safety of your drinking water. Your well water samples will then be analyzed for: • 21 routine chemical and physical parameters (i.e. calcium, sulfate, fluoride) • 23 trace elements (i.e. arsenic, uranium) and • 2 specific types of arsenic
Confidentiality	• Only employees of Alberta Health & Wellness who work on this project will have access to your personal contact information including land location. This information will not be released to any individual or agency. • Your local public health officers in Alberta Health Service will access to your testing results and your personal contact information if you would like to have their assistance with interpreting your testing results, well maintenance and treatment options. • Your survey responses and water well test results will be published in a summary format which will not identify individuals or their water well results. • You should be aware that the water well sample results and legal land description will be shared with Alberta Environment if you agree with it. If you are not willing to share your legal land description, your property identification will not be used for publication.
Benefits	Many members of your community have expressed concern about high levels of arsenic and or uranium in their well water supplies. This program will help in identifying wells which do have high levels of these elements and what steps private home owners should take to reduce the levels in their drinking water. Each participant will receive a copy of the laboratory analysis along

	with an interpretation guide as to what the results mean. If your well tests above current drinking water standards, this will be clearly identified in the letter to you. You should receive a copy of these results within 10 weeks of the samples being taken.
Risks	There are no direct risks to you if you decide to become involved. You may become more aware about some issues related to drinking water. This higher awareness is not expected to be harmful to you.
Withdrawal from the survey	At any time, you can decide that you do not wish to continue in this survey. You do not need to provide a reason as to why you do not want your information used. Alberta Health & Wellness will disregard your survey responses and well water test results immediately.
Use of the Information	The results of this survey will inform the Government of Alberta about the water quality in the Beaver River Basin. This will aid the Government of Alberta in determining the best way to improve and or protect groundwater in this area. A summary of this information may also be used in presentations or publications for academic or peer-reviewed journals.

Participant Consent Form

Participant ID______________Date______________Phone#_______________________
Name_______________________
Address____
Legal land Description_____________________________
GPS______________________________

Title of Project: **Domestic Well Water Quality Monitoring and Human Health Risk Assessment – The Beaver River Basin Region**
Principal Investigator: **Surveillance & Assessment Branch, Alberta Health and Wellness**

(Please mark x in box)

Do you understand that you have been asked to be apart of survey? Yes☐ No☐

Have you read a copy of the attached Information Sheet? Yes☐ No☐

Do you understand the benefits involved in taking part in this project? Yes☐ No☐

Have you had an opportunity to ask questions and discuss this project? Yes☐ No☐

Do you understand that the samples will be tested for some chemicals? Yes☐ No☐

Do you understand that you are free to refuse to participate or withdraw from this survey at any time? Yes☐ No ☐

Has the issue of confidentiality been explained to you? Do you understand who will have access to your results? Yes☐ No ☐

Do you want to disclose your test results and your personal contact information to your local public health officers? Yes☐ No☐

Do you want to disclose your test results to Alberta Environment? Yes☐ No☐

Do you want to disclose your legal land description to Alberta Environment? Yes☐ No☐

Who explained this study to you? _____________________________

I agree to take part in this project. Yes ☐ No ☐

_____________________________ _______________ _________________________
Signature of Participant Date Printed Name

I believe that the person signing this form understands what is involved in the project and voluntarily agrees to participate.

_____________________________ _______________ _________________________
Witness Date Printed Name

Site Visit Questionnaire

Participant ID (label) Date
Legal Land Description
Handheld GPS coordinates

Q	Question	Response	Code
	For Homeowner Use		
1	Have you tested chemicals in your well water before? (if yes, record the test results in the " Previous Test Results" sheet. If you have an extra copy, please provide)	☐ No ☐ Yes (go to PT sheet) ☐ Do not know ☐ No answer	1 2 77 99
2	When was your well first drilled?	year	
3	How deep is your well?	________ ft ________m	
4	What is your well ID number?	ID#	
5	At what depth is your pump set?		
6	Have you ever had to lower your pump or deepen your well?	☐ No (go to 7) ☐ Yes (go to 6a) ☐ Do not know ☐ No answer	1 2 77 99
6a	If yes, when and why?		
7	Do you have any issues about your well water quality? (odor, colour, taste or quantity)?	☐ No (go to 7b) ☐ Yes (go to 7a) ☐ Do not know (go to 7b) ☐ No answer (go to 7b)	1 2 77 99
7a	If yes, please describe it:		
7b	Is there a sulphur (rotten egg) odor from the water?	☐ No ☐ Yes ☐ Do not know ☐ No answer	1 2 77 99
7c	Is there greasy slime growth on the toilet flush tank?	☐ No ☐ Yes ☐ Do not know ☐ No answer	1 2 77 99
7d	Have you noticed a decrease in well yield?	☐ No ☐ Yes ☐ Do not know ☐ No answer	1 2 77 99
8	Has there been recent flooding or high water around the well?	☐ No ☐ Yes ☐ Do not know ☐ No answer	1 2 77 99
9	Are there any groundwater wells on your property no longer in use?	☐ No ☐ Yes (go to 9a) ☐ Do not know ☐ No answer	1 2 77 99
9a	Have they been plugged/backfilled in?	☐ No ☐ Yes ☐ Do not know ☐ No answer	1 2 77 99
10	When was the last time the well was shock chlorinated?	Year Month	

11	Do you treat the water from your well?	☐ No (go to 13) ☐ Yes (go to 12) ☐ Do not know (go to 13) ☐ No answer (go to 13)	1 2 77 99
12	How do you treat your well water?	Softener☐	1
		Chlorinator ☐	2
		Distiller ☐	3
		Carbon filter ☐	4
		Iron filter ☐	5
		Reverse osmosis ☐	6
	If others, please describe:		99
13	What is the normal source of the water that you drink? *(check all that apply)*		
		☐ Cold tap water from the well (ask 14 & 15)	1
		☐ Boiled tap water from the well (ask 14 & 15)	2
		☐ Bottled water(ask 14&16)	3
		☐ Tap water from not-your-well (ask 14 & 17)	4
	If other sources, please describe:		98
14	Approximately how much total **liquid** (water, coffee, tea, juice, soft drink, wine, beer etc) do you drink **each day?** (1 cup=250 ml)?	__________ L **OR**	
	If not know exact amount, please estimate:	☐ Less than 2 cups	1
		☐ 3 - 4 cups	2
		☐ 5 - 6cups	3
		☐ 7 - 8 cups	4
		☐ Greater than 8 cups	5
15	Approximately how much well water from the **kitchen tap** do you drink **each day**?	__________ L **OR**	
	If not know exact amount, please estimate:	☐ Less than 2 cups	1
		☐ 3-4 cups	2
		☐ 5-6cups	3
		☐ 7-8 cups	4
		☐ Greater than 8 cups	5
16	Approximately how much **bottled** water do you drink?	__________ L **OR**	
	If not know exact amount, please estimate:	☐ Less than 2 cups	1
		☐ 3-4 cups	2
		☐ 5-6 cups	3
		☐ 7-8 cups	4
		☐ Greater than 8 cups	5
17	Approximately how much **water from not-your-well** (e.g. tap in workplace) do you drink **each day**?	__________ L **OR**	
	If not know exact amount, please estimate:	☐ Less than 2 cups	1
		☐ 3-4 cups	2
		☐ 5-6cups	3
		☐ 7-8 cups	4
		☐ Greater than 8 cups	5
18	What do you use **kitchen tap water** from well for? (Check all that apply)	☐ Drinking	1
		☐ Cooking	2
		☐ Washing food	3

		☐ Making beverage (go to 18a)	4
		☐ Brushing teeth	5
		☐ Laundry	6
		☐ Bathing/showering	7
	If others, please describe:		99
18a	If you use **kitchen tap** water to make coffee, tea, reconstituted juice and soups **each day**, approximately how much kitchen tap water do you use to make them?	Coffee _____L______Cup Tea _____L______Cup Juice _____L______Cup Soup _____L______Cup Others _____L______Cup	
19	How many people live in this house?	____ Adults	
		____ Non-adults (<18)	
	For Survey Technician Use		
20	Casing type		
		☐ Steel OD in/mm	1
		☐ PVC	2
		☐ Concrete	3
		☐ CSP	4
		☐ Wood	5
		☐ Other (describe)	6
		☐ Do not know	77
		☐ No answer	99
21	Is the well in a pit?	☐ No (go to 22) ☐ Yes (go to 21a) ☐ Do not know (go to 22) ☐ No answer (go to 22)	1 2 77 99
21a	What else is in the pit? Please describe:		
22	Any sign of external contamination? (e.g. Feces, droppings)	☐ No (go to 23) ☐ Yes (go to 22a) ☐ Do not know (go to 23) ☐ No answer (go to 23)	1 2 77 99
22a	If yes, please describe:		
23	What else is in close proximity to the well? *See list below, and check off what applies and include approximate distance.*		
	Distance from septic tank/field/discharge	_____ ft ______m	
	Distance from fuel storage	_____ ft ______m	
	Distance from manure storage	_____ ft ______m	
	Distance from fertilizer storage	_____ ft ______m	
	Distance from animal pens	_____ ft ______m	
	Distance from waste disposal pit (i.e. dry waste)	_____ ft ______m	
	Other: ___________________________________	_____ ft ______m	
	Other: ___________________________________	_____ ft ______m	

Questions from Well Owner	**Referred to:**

Participant ID (label)

Previous Lab Test Results

Owner Name____________
Well ID________________
Test Date_______________
Lab Name_______________

(if having a photocopy of the results, please keep the hard copy. If no, please write down the results in the table below. Please check the unite as mg/l. If not mg/l, please write down the unit.)

No.	Element	Symbol	Result mg/l
1	Aluminum	Al	
2	Antimony	Sb	
3	Arsenic	As	
4	Barium	Ba	
5	Beryllium	Be	
6	Boron	B	
7	Cadmium	Cd	
8	Chromium	Cr	
9	Cobalt	Co	
10	Copper	Cu	
11	Iron	Fe	
12	Lead	Pb	

No.	Element	Symbol	Result mg/l
13	Manganese	Mn	
14	Mercury	Hg	
15	Molybdenum	Mo	
16	Nickel	Ni	
17	Selenium	Se	
18	Silver	Ag	
19	Thallium	Tl	
20	Titanium	Ti	
21	Uranium	U	
22	Vanadium	V	
23	Zinc	Zn	

APPENDIX B

Sampling Protocols

ACFT
Alberta Centre For Toxicology

HM-B19, 3330 Hospital Drive NW, Calgary, Alberta Canada T2N 4N1 T: (403) 220.5511 - F: (403) 270.2964 E: acft@ucalgary.ca

Collection Procedure for Routine Analysis of Drinking Water

The printed instructions for collecting a water sample are on the first page of the "Request for Chemical Analysis of Drinking Water for Human Consumption" requisition form.

SUPPLIES:

- One polyethylene terephthalate (PET) clear bottle (63mm neck), 500mL.
- One tri-wall plain ziplock bag.
- Requisition form titled "Request for Chemical Analysis of Drinking Water for Human Consumption."

PROCEDURES:

Water collection:

- Care should be taken to avoid touching the inside of the screw cap or mouth of the bottle. Use only the special bottle available from your local public health office.
- Indicate on the bottle that sample is for Routine analysis.
- If collection is from pump or tap, allow water to flow for about five minutes before taking sample.
- Fill the bottle completely and cap tightly.

REQUISITION:

- Detach the first sheet from the Requisition Form.
- Attach one ID No. Label from the form to the indicated space on the sample bottle.
- Attach the other ID No. Label on the lid.
- Complete the requisition including the homeowner's name, address, postal code and phone number.
  If the sample is treated water, please provide specifics of treatment.
- Legal Land Description must be provided.
- Ensure the Public Health Office/Regional Health Authority name and address (stamp) is indicated on the yellow copy of the form.
- Form must be authorized by the Public Health Official or Designate.

DELIVERY OF WATER SAMPLE:

- Deliver sample to your local public health office as soon as possible following collection.
- Transportation of the samples to the Alberta Centre for Toxicology for testing is the responsibility of the submitting public health office.
- Transport samples in a leak proof shipping container.

NOTE: Samples are stable at room temperature and do not require any special handling or storage.

Analytical and Environmental Toxicology, University of Alberta

Collection of water samples for determination of As(III) and As(V) species

Inorganic As(III) and As(V) are the predominant arsenic species in water. These two arsenic species in water samples are not stable and can be inter-converted if the water sample is not treated. To preserve the original AS(III) and As(V) species in the water sample, we add to the water sample acetic acid and EDTA to the final concentrations of 87 mM acetic acid and 1.34 mM EDTA. The use of these preservatives have been shown to stabilize As(III) and As(V) species in water samples (1-3). Sampling containers will be 250-mL polypropylene (PP) bottles. Two such 250-mL polypropylene bottles, each containing 10.8 mL of
2.0 M acetic acid and 3.35 mL of 0.1 M EDTA solutions, will be used at each sampling site.

Procedures:

- Open water tap and let water run for about 1 minute.
- Fill the first bottle with water sample. Do not over fill the bottle. Cap the bottle.
- Fill the second bottle with water sample. Do not over fill the bottle. Cap the bottle.
- Using a permanent colour marker pen, write on both bottles:
  sampling site, date and time, name of collector
- Record the above sampling information on your log book.
- Put both bottles containing water in a refrigerator (4 C), and deliver the samples to the University of Alberta laboratory (Dr. Chris Le) within one week of sample collection. If there is no refrigeration facility, deliver the samples to the University of Alberta (Dr. Chris Le) within the same day.

The arsenic species in the water samples will be determined by using the method of liquid chromatography separation and inductively coupled plasma mass spectrometry detection (4-6).

1. Gallagher, P. A.; Schwegel, C. A.; Parks, A.; Gamble, M.; Wymer, L.; Creed, J. T. Preservation of As(III) and As(V) in drinking water supply samples from across the United States using EDTA and acetic acid as a means of minimizing iron−arsenic coprecipitation. *Environ. Sci. Technol.* **2004**, *38*, 2919−2927.
2. Gautam Samanta, G.; Clifford, D.A. Preservation of Inorganic Arsenic Species in Groundwater**.** *Environ. Sci. Technol.*, **2005**, *39* (22), pp 8877–8882
3. Gautam Samanta, G.; Clifford, D.A. Preservation and Field Speciation of Inorganic Arsenic Species in Groundwater. *Water Qual. Res. J. Canada,* **2006**, *41,* No. 2, 107-116.
4. Xia, Y.; Wade, T.J.; Wu, K.; Li, Y.; Ning, Z.; Le, X.C.; He, X.; Chen, B.; Feng, Y.; Mumford, J.L. Well water arsenic exposure, arsenic induced skin-lesions and self-reported morbidity in Inner Mongolia. *Int. J. Environ. Res. Public Health* **2009**, *6*, 1010-1025.
5. Gong, Z.; Lu, X.; Watt, C.; Wen, B.; He, B.; Mumford, J.; Ning, Z.; Xia, Y.; Le, X.C. Speciation analysis of arsenic in groundwater from Inner Mongolia with an emphasis on acid-leachable particulate arsenic. *Anal. Chim. Acta* **2006**, *555*, 181-187.
6. Le, X.C.; Ma, M. Short-column liquid chromatography with hydride generation atomic fluorescence detection for the speciation of arsenic. *Anal. Chem.* **1998**, ***70***, 1926-1933.

APPENDIX C

Land Formation Description

Marine	LaBiche Formation	Klb	Dark grey shale and silty shale; ironstone partings and concretions; silty fish-scale bearing beds ; marine
	Lea Park Formation	Klp	Dark grey shale; pale grey, glauconitic silty shale with ironstone concretions; marine
Non Marine	Belly River Formation	Kbr	Grey to greenish grey, thick-bedded, feldspathic sandstone; grey clayey siltstone, grey and green mudstone; concretionary ironstone beds; nonmarine

Source: Hamilton *et. al.* 1999, Geological Map of Alberta, Alberta Geological Survey

APPENDIX D

Chemical Levels Before and After Treatment

Table A Treatment Methods and Alkalinity, TDS and Bicarbonate

No	S	C	D	CF	IF	RO	Alk raw	Alk tre	% RD	TDS raw	TDS tre	% RD	BC raw	BC tre	% RD
01	X				X	X	485	30	*94*	899	51	*94*	571	37	*94*
02	X		X				484	1.3	*100*	587	5	*99*	590	1.6	*100*
03	X			X	X	X	669	49	*93*	1125	67	*94*	817	60	*93*
04	X	X	X	X	X		592	23	*96*	728	15	*98*	721	28	*96*
05	X	X	X		X		560	1.4	*100*	573	3	*99*	683	1.7	*100*
06	X		X	X			415	3.0	*99*	746	2	*100*	507	3.1	*99*
07	X			X		X	623	89	*86*	1468	428	*71*	760	109	*86*
08						X	354	17	*95*	354	19	*95*	431	21	*95*
09	X				X	X	678	56	*92*	1112	80	*93*	827	68	*92*
10	X			X			638	13	*98*	819	16	*98*	779	15	*98*
11	X				X	X	633	66	*90*	1503	95	*94*	772	80	*90*
12	X					X	527	18	*97*	1336	59	*96*	625	21	*97*
13	X				X	X	669	72	*89*	732	76	*90*	816	88	*89*
14	X					X	636	112	*82*	1288	225	*83*	775	136	*82*
15	X					X	744	68	*91*	1607	131	*92*	907	83	*91*
16	X		X		X		414	1.5	*100*	403	1	*100*	505	1.9	*100*
17	X		X		X		524	2.2	*100*	1162	3	*100*	637	2.6	*100*
18	X					X	676	51	*93*	1146	83	*93*	824	62	*93*
19	X		X				433	23	*95*	2827	15	*99*	528	28	*95*
mean							**566**	**37**	***94***	**1074**	**72**	***93***	**688**	**45**	***94***

S=softener, C=chlorinator, D=distiller, CF=carbon filter, IF=iron filter, RO=reverse osmosis, alk=alkalinity, BC=bicarbonate, tre=treated, % RD= percentage of reduction after treatment, unit of alkalinity, TDS and bicarbonate = mg/L

Table B Treatment Methods and Hardness

ID	S	C	D	CF	IF	RO	HD raw	HD tre	% RD	Ca raw	Ca tre	% RD	Mg raw	Mg tre	% RD
1	X						689	1.1	*100*	139	0.22	*100*	83	0.13	*100*
2	X				X		538	7.2	*99*	135	1.35	*99*	49	0.92	*98*
3	X				X		162	1.6	*99*	41	0.43	*99*	15	0.13	*99*
4	X						573	8.8	*98*	131	2.2	*98*	60	0.81	*99*
5	X				X		439	2.2	*100*	108	0.64	*99*	41	0.15	*100*
6	X				X		532	1.4	*100*	109	0.39	*100*	63	0.11	*100*
7	X				X	X	152	5.1	*97*	37	1.22	*97*	14	0.5	*97*
8	X						118	4.1	*97*	29	1	*97*	11	0.39	*96*
9	X						405	11.9	*97*	91	2.66	*97*	43	1.28	*97*
10	X				X		432	3.0	*99*	106	0.76	*99*	41	0.26	*99*
11	X		X				341	0.4	*100*	82	0.1	*100*	33	0.04	*100*
12	X				X		356	195	*45*	92	41.3	*55*	30	22.3	*27*
13	X						443	1.6	*100*	100	0.36	*100*	47	0.16	*100*
14	X			X	X	X	766	25.7	*97*	195	6.47	*97*	68	2.32	*97*
15	X	X	X	X	X		241	0.1	*100*	59	nd	*100*	23	nd	*100*
16	X						628	1.8	*100*	164	0.46	*100*	53	0.15	*100*
17	X	X	X		X		516	nd	*100*	125	nd	*100*	50	nd	*100*

18	X						368	15.6	*96*	93	4.25	*95*	33	1.2	*96*
19	X						380	1.6	*100*	92	0.38	*100*	37	0.16	*100*
20	X			X			641	10.8	*98*	161	2.8	*98*	58	0.92	*98*
21	X						622	14.1	*98*	159	3.69	*98*	55	1.17	*98*
22	X						497	1.1	*100*	135	0.35	*100*	39	0.06	*100*
23	X				X		760	10.5	*99*	173	2.31	*99*	80	1.15	*99*
24	X						488	481	*1*	107	106	*1*	53	52.2	*2*
25	X		X	X			463	0.1	*100*	114	nd	*100*	43	nd	*100*
26	X				X		558	67.9	*88*	141	5.25	*96*	50	13.3	*73*
27	X						802	0.6	*100*	213	0.17	*100*	66	nd	*100*
28	X						524	3.3	*99*	129	0.93	*99*	49	0.25	*99*
29	X				X		463	54.9	*88*	117	11.9	*90*	42	6.12	*85*
30	X				X		1710	19.6	*99*	420	5.21	*99*	161	1.61	*99*
31	X				X		199	203	*-2*	51	51.3	*-1*	18	18.2	*-3*
32	X						316	8.7	*97*	78	2.21	*97*	29	0.76	*97*
33	X						548	20.4	*96*	145	4.51	*97*	45	2.23	*95*
34	X						467	21.0	*96*	109	4.99	*95*	47	2.07	*96*
35	X			X		X	1081	5.1	*100*	243	0.48	*100*	115	0.94	*99*
36	X						816	700	*14*	179	135	*25*	90	88.2	*2*
37	X						442	8.3	*98*	114	2.01	*98*	38	0.79	*98*
38	X						557	12.9	*98*	126	2.92	*98*	59	1.36	*98*
39	X						731	17.5	*98*	184	4.42	*98*	66	1.56	*98*
40	X						619	28.3	*95*	142	6.33	*96*	64	3.02	*95*
41	X				X		507	28.5	*94*	126	6.73	*95*	47	2.85	*94*
42	X						551	20.3	*96*	114	5.2	*95*	65	1.77	*97*
43	X				X		303	1.8	*99*	75	0.52	*99*	28	0.11	*100*
44	X						464	0.5	*100*	115	0.15	*100*	43	nd	*100*
45	X						613	634	*-3*	139	141	*-2*	65	68.4	*-6*
46	X						470	22.4	*95*	127	6.01	*95*	37	1.79	*95*
47	X						429	1.0	*100*	102	0.25	*100*	42	0.1	*100*
48	X						406	138	*66*	100	28.6	*71*	38	16.1	*58*
49	X						303	2.0	*99*	82	0.63	*99*	24	nd	*100*
50	X				X		118	6.3	*95*	30	1.56	*95*	10	0.58	*94*
51	X				X	X	658	2.0	*100*	187	0.42	*100*	47	0.23	*100*
52	X			X			631	0.2	*100*	155	nd	*100*	59	nd	*100*
53	X				X	X	947	1.8	*100*	254	0.42	*100*	76	0.19	*100*
54	X					X	290	0.2	*100*	73	nd	*100*	26	nd	*100*
55	X						1215	25.2	*98*	255	4.5	*98*	140	3.39	*98*
56	X						923	16.8	*98*	164	2.05	*99*	125	2.83	*98*
57	X						1114	15.1	*99*	240	2.57	*99*	125	2.11	*98*
58	X				X		720	11.8	*98*	181	3.01	*98*	65	1.04	*98*
59	X				X	X	532	0.2	*100*	133	nd	*100*	49	nd	*100*
60	X						168	66.2	*61*	41	15.9	*62*	16	6.45	*59*
61	X				X		480	472	*2*	124	122	*1*	42	40.6	*3*
62	X					X	343	0.9	*100*	87	0.23	*100*	31	0	*100*
63	X						501	3.8	*99*	123	0.89	*99*	47	0.38	*99*
64	X				X		357	58.8	*84*	91	10.8	*88*	32	7.75	*75*

65	X						400	2.5	*99*	93	0.58	*99*	41	0.25	*99*
66	X						487	252	*48*	124	56.2	*55*	43	27.1	*37*
67	X						487	14.2	*97*	123	3.21	*97*	44	1.49	*97*
68	X				X		720	8.9	*99*	147	1.83	*99*	86	1.06	*99*
69	X					X	1225	43.1	*96*	259	9.79	*96*	141	4.53	*97*
70	X		X		X		382	0.2	*100*	89	nd	*100*	39	nd	*100*
71	X						528	17.0	*97*	111	4.22	*96*	61	1.58	*97*
72	X				X		453	10.4	*98*	105	2.36	*98*	46	1.09	*98*
73	X						376	8.6	*98*	95	2.19	*98*	34	0.77	*98*
74	X			X			711	17.9	*97*	140	3.56	*97*	88	2.18	*98*
75	X				X		846	28.6	*97*	216	8.02	*96*	74	2.07	*97*
76	X						572	21.0	*96*	151	5.08	*97*	47	2.02	*96*
77	X						462	18.7	*96*	116	5.17	*96*	42	1.4	*97*
78	X		X		X		768	0.1	*100*	202	nd	*100*	64	nd	*100*
79	X					X	204	0.3	*100*	51	nd	*100*	18	nd	*100*
80	X				X		1159	72.6	*94*	297	18.4	*94*	102	6.48	*94*
81	X				X		804	9.0	*99*	225	2.89	*99*	59	0.44	*99*
82	X						986	23.0	*98*	165	4.24	*97*	139	3.02	*98*
83	X		X				488	0.1	*100*	118	nd	*100*	47	nd	*100*
84	X						430	1.2	*100*	107	0.39	*100*	40	nd	*100*
85	X						504	4.3	*99*	122	1.12	*99*	48	0.37	*99*
86	X						195	4.8	*98*	50	1.38	*97*	17	0.33	*98*
87	X						704	19.3	*97*	194	4.73	*98*	53	1.82	*97*
88	X						1177	46.5	*96*	301	13.8	*95*	104	2.91	*97*
89	X				X		1205	51.7	*96*	315	9.55	*97*	102	6.77	*93*
90	X						864	48.5	*94*	232	12.5	*95*	69	4.21	*94*
91	X			X			749	36.6	*95*	190	9.16	*95*	67	3.34	*95*
92	X						691	11.9	*98*	181	3.31	*98*	58	0.87	*99*
93	X				X		313	5.3	*98*	77	1.44	*98*	29	0.42	*99*
94	X						593	1.5	*100*	155	0.43	*100*	50	0.11	*100*
95	X						266	1.2	*100*	67	0.27	*100*	24	0.12	*100*
96	X						294	1.1	*100*	75	0.34	*100*	26	nd	*100*
97	X						473	4.7	*99*	116	1.23	*99*	44	0.4	*99*
98	X				X		778	5.8	*99*	193	1.3	*99*	72	0.62	*99*
99	X						475	7.9	*98*	123	2.19	*98*	41	0.6	*99*
100	X						318	0.8	*100*	89	0.24	*100*	23	nd	*100*
101	X				X		354	4.7	*99*	91	0.81	*99*	31	0.64	*98*
102	X				X		436	11.6	*97*	98	1.28	*99*	46	2.04	*96*
103	X						1351	90.3	*93*	239	17.8	*93*	183	11.1	*94*
Mean							**569**	**43**	***92***	**137**	**10**	***92***	**55**	**5**	***91***

S=softener, C=chlorinator, D=distiller, CF=carbon filter, IF=iron filter, RO=reverse osmosis, HD=hardness, Ca=calcium, Mg=magnesium, tre=treated, % RD= percentage of reduction after treatment, unit of hardness, calcium and magnesium = mg/L

Table C Treatment Methods and Sodium and Potassium

No	S	C	D	CF	IF	RO	Na raw	Na tre	% INC	% RD	K raw	K tre	% INC	% RD
1	X						137	468	*71*		8.5	0.3		*96*
2	X				X		137	392	*65*		4.8	1.7		*64*
3	X				X		426	496	*14*		3.5	0.7		*79*
4	X						54	329	*83*		6.4	1.9		*70*
5	X				X		18	26	*31*		3.9	348	*99*	
6	X				X		28	197	*86*		5.1	120	*96*	
7	X				X	X	290	19		*93*	3.6	0.2		*93*
8	X						310	334	*7*		3.5	54	*93*	
9	X						53	287	*82*		6.6	0.7		*89*
10	X				X		65	11		*83*	3.9	432	*99*	
11	X		X				95	1.7		*98*	3.6	0.1		*98*
12	X				X		203	191		*6*	4.4	149	*97*	
13	X						34	238	*86*		5.4	5.3		*2*
14					X		62	68	*8*		3.7	4.0	*7*	
15	X			X	X	X	93	16		*83*	5.0	1.3		*75*
16	X	X	X	X	X		188	0.2		*100*	4.4	0.3		*94*
17				X	X		12	13	*4*		5.1	5.2	*3*	
18	X						77	364	*79*		4.2	1.1		*73*
19	X	X	X		X		23	0.5		*98*	5.1	0.7		*86*
20	X						209	243	*14*		5.7	195	*97*	
21	X						7	189	*96*		4.5	0.9		*81*
22	X			X			154	469	*67*		5.4	1.4		*73*
23	X						143	408	*65*		4.7	3.5		*25*
24	X						44	273	*84*		3.9	0.1		*97*
25	X				X		179	557	*68*		4.9	0.9		*83*
26	X						22	21		*1*	3.9	3.9	*2*	
27					X		290	301	*4*		4.0	4.2	*4*	
28	X		X	X			85	0.1		*100*	3.4	nd		
29	X				X		22	38	*44*		5.1	346	*99*	
30	X						104	497	*79*		5.5	1.0		*81*
31	X						82	333	*75*		4.4	0.3		*92*
32	X				X		153	354	*57*		6.2	3.9		*37*
33	X				X		143	808	*82*		10.7	1.1		*89*
34	X				X		332	337	*1*		4.4	4.6	*5*	
35	X						311	416	*25*		4.8	61	*92*	
36	X						97	58		*41*	4.9	521	*99*	
37	X						16	3.2		*80*	6.9	395	*98*	
38	X			X		X	143	22		*85*	7.0	207	*97*	
39	X						87	90	*3*		9.5	63	*85*	
40	X						170	194	*12*		6.6	304	*98*	
41	X						81	326	*75*		5.1	0.6		*89*
42	X						296	564	*48*		6.9	86	*92*	
43						X	12	3.2		*74*	3.0	1.3		*59*

44	X						77	340	*77*		3.7	1.5		*60*
45	X				X		14	242	*94*		5.2	0.3		*94*
46	X						136	73		*46*	3.6	535	*99*	
47	X				X		272	17		*94*	4.8	652	*99*	
48	X						29	234	*88*		4.7	1.0		*78*
49	X						15	16	*6*		5.0	5.3	*6*	
50	X						11	13	*12*		7.8	323	*98*	
51	X						76	332	*77*		5.5	1.3		*77*
52	X						9	125	*93*		2.8	17	*84*	
53	X						253	35		*86*	5.0	613	*99*	
54	X				X		356	403	*12*		3.3	1.9		*42*
55					X		35	33		*4*	3.3	3.3		*1*
56	X				X	X	190	33		*83*	3.7	0.1		*97*
57							45	46	*3*		12.5	13	*3*	
58	X			X			65	7		*89*	4.2	nd		*100*
59	X				X	X	139	39		*72*	7.1	0.5		*93*
60				X			13	13	*4*		6.1	6.8	*9*	
61	X					X	388	9		*98*	4.6	19.2	*76*	
62	X						174	750	*77*		6.8	1.0		*86*
63	X						112	548	*80*		6.3	0.6		*90*
64	X						70	571	*88*		12.8	3.4		*74*
65	X				X		69	406	*83*		4.8	1.2		*75*
66	X				X	X	69	30		*56*	5.4	nd		
67	X						124	156	*21*		3.1	1.0		*69*
68	X				X		95	94		*2*	5.4	5.3		*1*
69	X					X	372	25		*93*	5.5	92	*94*	
70	X						316	77		*76*	1.2	4.8	*75*	
71	X				X		633	758	*17*		5.0	3.9		*22*
72					X		137	137	*0*	*0*	6.2	5.6		*9*
73	X						10	4		*64*	4.0	332	*99*	
74	X						13	108	*88*		4.3	15	*72*	
75	X						46	18		*62*	5.2	422	*99*	
76	X				X		130	457	*72*		8.3	6.8		*18*
77	X					X	83	33		*60*	5.3	2.2		*58*
78	X		X		X		9	nd			6.2	nd		*100*
79	X						23	8		*67*	4.6	440	*99*	
80	X				X		23	230	*90*		4.1	1.3		*70*
81	X						130	97		*25*	4.5	367	*99*	
82	X			X			55	11		*81*	10.9	586	*98*	
83	X				X		40	443	*91*		6.9	2.1		*70*
84	X						300	282		*6*	5.1	472	*99*	
85	X						121	93		*23*	6.3	384	*98*	
86	X		X		X		84	nd			6.7	nd		
87	X					X	360	23		*94*	4.3	14	*70*	
88	X				X		136	640	*79*		11.1	1.5		*86*
89	X				X		121	14		*88*	4.2	761	*99*	
90	X						76	525	*86*		6.5	1.0		*85*

91				X	X		394	389		*1*	5.6	5.6		*0*
92	X		X				895	nd			6.7	nd		
93	X						15	236	*94*		3.5	0.2		*94*
94	X						57	295	*81*		5.0	1.1		*78*
95	X						565	637	*11*		4.1	1.0		*75*
96	X						172	522	*67*		5.8	1.5		*75*
97	X						120	38		*68*	8.1	1055	*99*	
98	X				X		174	372	*53*		7.4	8.6	*14*	
99	X						668	1088	*39*		17.7	49	*64*	
100	X			X			21	377	*94*		4.8	0.8		*84*
101	X						184	499	*63*		3.9	1.7		*57*
102	X				X		9	175	*95*		9.1	4		*56*
103	X						41	310	*87*		6.3	0.8		*87*
104	X						31	158	*80*		2.8	0.9		*68*
105	X						397	534	*26*		4.8	2.0		*59*
106	X						118	325	*64*		5.1	0.8		*84*
107	X				X		79	445	*82*		4.6	0.2		*96*
108		X		X			57	59	*3*		12.3	13	*5*	
109	X						48	277	*83*		5.4	1.9		*64*
110	X						26	180	*86*		10.1	0.4		*96*
111	X				X		226	413	*45*		5.8	1.7		*71*
112	X				X		17	214	*92*		3.3	1.0		*70*
113	X						156	43		*72*	8.6	1150	*99*	
Mean							**141**	**235**	***57***	***61***	**5.6**	**109**	**73**	**70**

S=softener, C=chlorinator, D=distiller, CF=carbon filter, IF=iron filter, RO=reverse osmosis, Na=sodium, K=potassium, tre=treated, % INC= percentage of increase after treatment, % RD= percentage of reduction after treatment, unit of sodium and potassium = mg/L

Table D Treatment Methods and Iron

No	S	C	D	CF	IF	RO	Fe Raw	Fe Tre	% RD
1	X						9.62	0.05	99
2	X				X		1.44	0.05	97
3	X				X		0.4	0.04	90
4	X						8.41	0.19	98
5	X				X		2.72	0.19	93
6	X				X		0.69	0.08	88
7	X				X	X	0.83	<0.01	100
8	X						0.68	0.03	96
9	X						1.14	0.07	94
10	X				X		3.25	0.04	99
11	X		X				0.87	<0.01	100
12	X				X		2.22	0.22	90
13	X						1.3	0.02	98
14					X		0.29	0.33	-14
15	X			X	X	X	5.66	<0.01	100
16	X	X	X	X	X		1.07	<0.01	100
17				X	X		0.48	<0.01	100
18	X						3.34	0.04	99
19	X	X	X		X		3.4	<0.01	100
20	X						1.26	0.05	96
21	X						0.27	0.01	96
22	X			X			1.94	0.06	97
23	X						3.26	0.06	98
24	X						0.59	0.01	98
25	X				X		0.02	0.06	-200
26							0.14	0.11	21
27					X		1.59	0.31	81
28	X		X	X			2.97	<0.01	100
29	X				X		6.56	0.22	97
30	X						11.35	0.02	100
31	X						6.64	0.16	98
32	X				X		3.05	0.09	97
33	X				X		6.55	0.02	100
34	X				X		0.89	<0.01	100
35	X						0.89	0.05	94
36	X						6.37	0.31	95
37	X						1.34	0.1	93
38	X			X		X	0.01	<0.01	100
39	X						0.27	0.01	96
40	X						2.53	0.07	97
41	X						0.27	<0.01	100
42	X						0.53	0.04	92
43						X	0.04	<0.01	100

44							0.66	<0.01	100
45	X						1.33	0.09	93
46	X				X		4.21	0.31	93
47	X						0.96	0.12	88
48	X				X		0.66	0.08	88
49	X						0.77	0.06	92
50	X						0.01	<0.01	100
51	X						0.19	0.01	95
52	X						0.83	0.02	98
53	X						0.13	0.06	54
54	X						1.92	0.27	86
55	X				X		0.07	0.15	-114
56					X		2.96	0.02	99
57	X				X	X	6.05	<0.01	100
58							<0.01	<0.01	n/a
59	X			X			0.08	<0.01	100
60	X				X	X	3.94	<0.01	100
61				X			1.43	<0.01	100
62	X					X	0.4	<0.01	100
63	X						<0.01	<0.01	n/a
64	X						<0.01	<0.01	n/a
65	X						<0.01	<0.01	n/a
66	X				X		2.97	0.02	99
67	X				X	X	3.63	<0.01	100
68	X						1.37	0.49	64
69	X				X		3.45	0.11	97
70	X					X	1.1	<0.01	100
71	X						0.08	<0.01	100
72	X				X		0.38	0.03	92
73					X		0.08	0.02	75
74	X						<0.01	<0.01	n/a
75	X						<0.01	<0.01	n/a
76	X						0.59	0.1	83
77	X				X		0.95	0.09	91
78	X					X	0.23	<0.01	100
79	X		X		X		2.37	<0.01	100
80	X						2.55	0.04	98
81	X				X		4.74	0.02	100
82	X						1.02	0.04	96
83	X			X			1.05	0.16	85
84	X				X		5.76	0.22	96
85	X						0.05	0.02	60
86	X						1.46	0.01	99
87	X		X		X		1.47	<0.01	100
88	X					X	0.53	<0.01	100
89	X				X		3	0.23	92
90	X				X		11.84	0.24	98

91	X						<0.01	<0.01	n/a
92				X	X		0.54	0.09	83
93	X		X				1.19	<0.01	100
94	X						1.06	0.09	92
95	X						0.78	0.02	97
96	X						0.91	0.07	92
97	X						10.64	0.47	96
98	X						0.06	0.05	17
99	X				X		16.96	0.07	100
100	X						<0.01	<0.01	n/a
101	X			X			4.12	0.01	100
102	X						4.05	0.1	98
103	X				X		8.97	0.34	96
104	X						4.77	0.09	98
105	X						2.24	0.03	99
106	X						0.4	0.03	93
107	X						2.13	0.1	95
108	X				X		3.19	0.01	100
109		X		X			1.13	1.9	-68
110	X						1.95	0.04	98
111	X						1.51	0.14	91
112	X				X		1.36	0.05	96
113	X				X		0.89	<0.01	100
114	X						<0.01	<0.01	n/a

S=softener, C=chlorinator, D=distiller, CF=carbon filter, IF=iron filter, RO=reverse osmosis, Fe=iron, tre=treated, % RD= percentage of reduction after treatment, unit of iron = mg/L

Table E Treatment Methods and Arsenic Species

No.	S	C	D	CF	IF	RO	As III raw	As V raw	As III) tre	As V tre	%RD As III	% RD As V	%INC As III	%INC As V
1	X						0.0167	0.0020	0.0169	0.0012		43	1	
2	X				X		0.0239	0.0023	0.0243	0.0025			2	9
3	X				X		0.0135	0.0019	0.0159	0.0035			15	45
4	X						0.0191	0.0052	0.0199	0.0020		62	4	
5	X				X		0.0007	0.0004	0.0010	0.0002		57	28	
6	X				X		0.0011	0.0011	0.0005	0.0015	57			25
7	X				X	X	0.0255	0.0024	nd	0.0004	100	83		
8	X						0.0221	0.0010	0.0178	0.0009	19	7		
9	X						0.0140	0.0113	0.0124	0.0052	11	54		
10	X				X		0.0044	0.0015	nd	0.0006	100	58		
11	X		X				0.0007	0.0016	nd	nd	100	100		
12	X				X		0.0001	nd	0.0003	nd			54	
13	X						0.0151	0.0065	0.0143	0.0051	6	22		
14					X		0.0123	0.0069	0.0166	0.0051		27	26	
15	X			X	X	X	0.0011	0.0003	nd	nd	100	100		
16	X	X	X	X	X		0.0159	0.0013	nd	nd	100	100		
17				X	X		0.0100	0.0005	0.0052	0.0010	48			51
18	X						0.0029	0.0003	0.0034	0.0002		36	13	
19	X	X	X		X		0.0104	0.0019	nd	nd	100	98		
20	X						0.0337	0.0073	0.0206	0.0117	39			37
21	X						0.0009	0.0002	0.0008	0.0002	12	4		
22	X			X			0.0010	0.0005	0.0004	0.0005	60			13
23	X						nd	0.0231	nd	0.0009		96		
24	X						0.0151	0.0093	0.0042	0.0146	72			36
25	X				X		0.0001	0.0002	0.0029	0.0010			95	79
26	X						0.0001	0.0003	0.0001	0.0002		26	1	
27					X		0.0003	0.0007	0.0014	0.0002		73	80	
28	X		X	X			0.0102	0.0018	nd	0.0001	100	95		
29	X				X		0.0054	0.0088	0.0004	0.0061	93	31		
30	X						0.0185	0.0028	0.0185	0.0025	0	12	0	
31	X						0.0133	0.0040	0.0004	0.0066	97			41
32	X				X		0.0081	0.0152	0.0053	0.0029	35	81		
33	X				X		0.0033	0.0008	nd	0.0003	100	66		
34	X				X		0.0072	0.0074	0.0003	0.0063	96	15		
35	X						nd	0.0001	nd	0.0001		7		
36	X						0.0236	0.0022	0.0225	0.0022	5	2		
37	X						0.0095	0.0016	0.0098	0.0003		78	3	
38	X			X		X	nd	0.0006	nd	0.0001		91		
39	X						0.0007	0.0019	0.0003	0.0014	59	28		
40	X						0.0419	0.0029	0.0289	0.0061	31			53
41	X						0.0006	0.0012	nd	0.0004	100	63		
42	X						0.0226	0.0095	0.0031	0.0312	86			70
43						X	0.0008	0.0005	0.0001	0.0007	87			28
44*							0.0005	0.0001	nd	0.0003	100			60

45	X						0.0003	0.0001	0.0003	nd	2	100		
46	X				X		0.0004	0.0010	0.0001	0.0001	69	87		
47	X						0.0090	0.0017	0.0090	0.0021	0		0	19
48	X				X		0.0140	0.0025	nd	0.0053	100			53
49	X						0.0048	0.0070	0.0025	0.0051	48	27		
50	X						nd	0.0002	nd	0.0002		5		
51	X						nd	0.0001	nd	0.0001				8
52	X						0.0305	0.0049	0.0323	0.0025		50	6	
53	X						0.0006	0.0007	0.0003	0.0003	44	50		
54	X						0.0048	0.0012	0.0012	0.0023	76			49
55	X				X		0.0003	0.0294	0.0001	0.0277	53	6		
56					X		0.0206	0.0034	nd	0.0013	100	61		
57	X				X	X	0.0314	0.0056	0.0097	0.0140	69			60
58							nd	nd	nd	nd				
59	X			X			nd	0.0025	nd	nd		100		
60	X				X	X	0.0123	0.0063	0.0002	nd	98	100		
61				X			0.0033	0.0005	0.0004	0.0001	89	71		
62	X					X	0.0097	0.0112	0.0001	nd	99	100		
63	X						nd	0.0006	nd	0.0001		83		
64	X						nd	0.0001	nd	0.0001				7
65	X						nd	0.0007	nd	0.0006		13		
66	X				X		0.0025	0.0010	0.0003	0.0047	89			79
67	X				X	X	0.0292	0.0024	0.0000	0.0005	100	80		
68	X						0.0137	0.0028	0.0135	0.0033	1			16
69	X				X		0.0217	0.0050	0.0042	0.0051	81			3
70	X					X	0.0131	0.0092	0.0002	0.0010	99	89		
71	X						0.0323	0.0037	0.0004	0.0007	99	80		
72	X				X		0.0099	0.0065	0.0002	0.0040	98	38		
73					X		nd	0.0001	nd	nd		100		
74	X						nd	nd	nd	nd				
75	X						nd	nd	nd	nd				
76	X						0.0257	0.0055	0.0271	0.0032		42	5	
77	X				X		0.0032	0.0009	0.0024	0.0014	25			31
78	X					X	0.0012	0.0004	nd	nd	100	100		
79	X		X		X		0.0111	0.0016	nd	0.0000	100	100		
80	X						0.0072	0.0006	0.0023	0.0023	68			75
81	X				X		0.0096	0.0055	0.0001	0.0007	99	87		
82	X						0.0004	nd	0.0004	nd			3	
83	X			X			0.0025	0.0015	0.0001	0.0022	96			30
84	X				X		0.0313	0.0031	0.0323	0.0012		61	3	
85	X						nd	nd	nd	nd				
86	X						0.0308	0.0052	0.0136	0.0034	56	34		
87	X		X		X		0.0049	0.0009	nd	nd	100	100		
88	X					X	0.0085	0.0063	0.0009	0.0026	90	58		
89	X				X		0.0175	0.0214	0.0319	0.0080		63	45	
90	X				X		0.0174	0.0191	0.0003	0.0102	98	46		
91	X						nd	nd	nd	nd				
92				X	X		0.0050	0.0011	0.0004	0.0001	92	87		

93	X		X				0.0003	0.0002	nd	nd	100	100		
94	X						0.0005	0.0010	0.0016	0.0001		90	66	
95	X						0.0371	0.0030	0.0334	0.0057	10			48
96	X						0.0283	0.0084	0.0339	0.0033		61	17	
97	X						0.0133	0.0048	0.0153	0.0007		86	13	
98	X						nd	nd	nd	nd				
99	X				X		0.0171	0.0027	nd	0.0002	100	94		
100	X						nd	0.0002	nd	nd		100		
101	X			X			0.0008	0.0130	nd	0.0007	100	95		
102	X						0.0263	0.0045	0.0155	0.0114	41			61
103	X				X		0.0076	0.0016	0.0059	0.0009	23	44		
104	X						0.0008	0.0001	0.0002	0.0000	74	100		
105	X						0.0099	0.0012	0.0102	0.0006		51	3	
106	X						nd	0.0003	0.0003	0.0002		51		
107	X						0.0037	0.0071	0.0038	0.0069		3	3	
108	X				X		0.0051	0.0024	0.0001	0.0002	97	90		
109		X		X			0.0084	0.0012	0.0008	0.0000	91	100		
110	X						0.0343	0.0052	0.0240	0.0041	30	21		
111	X						0.0002	nd	0.0003	nd			33	
112	X				X		0.0283	0.0164	0.0307	0.0125		24	8	
113	X				X		0.0004	0.0003	0.0002	nd	57	100		
114	X						nd	0.0002	nd	0.0002		7		
Mean							**0.0096**	**0.0036**	**0.0055**	**0.0025**	**70**	**62**	**20**	**40**

S=softener, C=chlorinator, D=distiller, CF=carbon filter, IF=iron filter, RO=reverse osmosis, tre=treated, % RD= percentage of reduction, % INC = percentage of increase, unit = mg/L, nd = <0.00001 mg/L
44*: water purification system was installed in this house, but no details were available.

Appendix E

Fact Sheet for Arsenic

Arsenic

1. What is arsenic?

Arsenic, with the chemical formula symbol “As”, is widely distributed in the earth’s crust. It is tasteless and odourless. Inorganic arsenic, which is combined with other elements like oxygen, chlorine or sulfur, is usually found in water, soil and air. Organic arsenic, which is combined with carbon and hydrogen, is usually found in plants, animals and most food.

2. How does arsenic enter groundwater?

Groundwater normally contains higher concentrations of inorganic arsenic than are found in surface water. Most Canadian groundwater contains arsenic at levels less than 0.005 milligrams per litre (< 5 ppb), but some range up to 1.0 milligrams per litre (~1000 ppb).

Localized high levels of inorganic arsenic have been found in well water from some regions in Alberta. Arsenic levels can vary from one well to the next, even within a very small area.

These elevated arsenic levels are often associated with arsenic-containing bedrock formations. Inorganic arsenic occurs naturally in many kinds of rock. Groundwater flowing through underground rock and soil can dissolve arsenic from the bedrock. Once in the water, arsenic does not evaporate or decompose and it cannot be removed by boiling water.

Arsenic may also get into water through man-made activities. In Canada, these activities include mining such as gold and base metal mining and agricultural use such as pesticides and feed additives.

3. How does arsenic get into and leave the body?

People ingest a small amount of arsenic (about 0.050 milligrams) every day. The sources of arsenic mainly come from the food you eat, particularly shellfish, and the water you drink. Sometimes, people may take in arsenic by breathing in smoke from burning arsenic-contaminated materials like treated wood.

The amount of inorganic arsenic taken in from drinking water alone by an average Canadian is probably about 0.007 to 0.035 milligrams each day. Consuming 2 litres per day of drinking water at the guideline level of 0.010 milligrams per litre would provide 0.020 milligrams of arsenic. Some people may take in higher levels of arsenic from some groundwater supplies.

Once arsenic is in the body, the liver changes some of this chemical to a less harmful form. Within seven days, most of the arsenic leaves the body via urine while some will remain in the body for several months or longer.

4. How could arsenic affect your health?

Organic arsenic is generally less harmful than inorganic arsenic. Swallowing a large amount of inorganic arsenic from food or water (above 60,000 micrograms per kilogram or micrograms per litre) can cause death, but this would be considered poisoning, not incidental arsenic consumption. At low exposure levels (300 to 30,000 micrograms per kilogram or micrograms per litre in food or water). A person may experience nausea, vomiting, diarrhea, decreased production of red and white cells, abnormal heart rhythm and a “pins and needles” sensation in hands and feet. Long-term exposure to inorganic arsenic can cause thickening and darkening of the skin.

Some studies indicate an increased risk of tumors of the skin, liver, bladder and lungs which can result from long-term exposure to relatively high levels of arsenic in water. Scientists continue to investigate the long-term health effects due to exposure to levels of arsenic less than 300 micrograms per litre. A few studies found no harmful health effects in persons in the Unites States, who drank water containing arsenic at levels of 50 to 100 micrograms per litre throughout their life time.

5. Does arsenic have any beneficial effects?

Arsenic is thought to be essential in trace amounts, but the benefits are not well understood. It is used in homeopathic treatments for some digestive problems including burning pain and symptoms of dehydration, and in cancer treatment as chemotherapy for acute promyelocytic leukemia. Most people receive enough arsenic from their diet to meet any normal beneficial needs.

6. What is the *Guideline for Canadian Drinking Water Quality* for arsenic?

In order to protect public health, a standard of 0.010 milligrams per litre (10 ppb) for the amount of arsenic in drinking water has been set, as a maximum acceptable concentration (MAC). This guideline provides a convenient yardstick against which water quality can be measured, so problems can be quickly identified and corrected.

7. **How to interpret the result?**

If you receive a result of greater than 0.010 milligrams per litre (10 ppb) for arsenic in the well water, it means that your health would not be directly affected by drinking water containing this level of arsenic. The guideline level is set at a level that is not expected to cause adverse health effects. It is difficult to predict whether or not arsenic in your drinking well water can affect you, or what the effects will be.

Most health problems from long-term exposure to arsenic through drinking water are health conditions that can have other possible causes and factors beside arsenic. Most common factors are diet, genes, lifestyle and current health conditions. How likely people are to experience health problems from exposure to arsenic in well water depends on:

- how much arsenic is in the well water;
- how much tap water you drink every day;
- how long you have been drinking the well water (this arsenic guideline level is set for drinking arsenic-containing water for 70 years); and
- how sensitive an individual is to arsenic.

More exposure to arsenic increases the chance that health problems may occur. If arsenic in the well water is over 10 micrograms per litre and you mainly use the well water for drinking, cooking and preparing food and beverages, it is recommended that the levels of arsenic be reduced or an alternative water source be used.

8. What do the results of arsenic species mean to you?

There are two main arsenic species in groundwater: +3 (arsenite) and +5 (arsenate). These species are the most harmful forms of arsenic to the human body. Arsenite is difficult to remove from water; and arsenate is easier to remove from water. Therefore, arsenite must be converted to arsenate before arsenic can be removed. Monitoring for arsenic species allows you to know how much arsenite and arsenate are in the well water. This helps you choose the proper methods to convert arsenite to arsenate to assure removal.

9. Can you use arsenic-rich well water for non-drinking activities?

Arsenic-rich well water may be used safely for laundry, bathing, showering, hand washing, dishwashing and watering a garden. Watch children during bathing in order to keep them from swallowing too much water.

10. What should you do if arsenic is high in the well water?

If the arsenic level is over the guideline level, you have to balance the potential health risk against cost and convenience in order to make a decision as to whether or not to continue to use the well water for drinking or cooking. If you have concerns about your health risk from drinking arsenic-rich well water, consult your family physician for advice.

The following recommendations will help you to make your own decisions:

- re-test well water once or twice per year;
- look for other types of water like bottled water, rain water, or treated surface water for drinking;
- look for an opportunity to connect to the public water supply if available and convenient;
- do not boil water because arsenic can be concentrated in boiled water;
- install an in-home treatment device to reduce arsenic levels in well water based on cost and difficulty;
- consult local public health officers for advice on water testing and well maintenance in order to select better options to reduce exposure to arsenic; and
- check your exposure levels of arsenic by having your urine tested.

11. What are treatment options?

If you choose to reduce the arsenic level in drinking well water, there are some short-term and long-term solutions. Well owners should work with local public health officers to find the best choices available because each method has its advantages and disadvantages. Well water treatment options are listed as follows:

Option	Advantage	Disadvantage
USE OTHER TYPES OF WATER		
bottled water, treated surface water, rain water	-arsenic-free water.	-inconvenient.
PRE-OXIDATION		
liquid chloride (bleach), hydrogen peroxide and ozone and chlorine	-efficiently remove inorganic arsenic by converting As+3 to As+5.	-arsenic not removed from water, must combine with other treatment devices.
INSTALL A POINT-OF-USE TREATMENT SYSTEM AT KITCHEN TAP		
	- affordable; and - remove arsenic below 10 ppb.	- treat water at a single kitchen tap; - produce small quantity of water; - regular maintenance and testing - does not remove arsenic; and completely if As is > 300 ppb.
reverse osmosis (RO) with pre-oxidation	- remove most minerals; - remove 98% of arsenic; and - easy to service.	- replace cartridge and membrane on schedules; - use copper/lead-free faucet; and - not known if health problems occur drinking mineral-free water.
adsorptive Media: activated alumina, granular ferric adsorption system, Iron oxide filter	- simplicity; - easy of operation and handling; - regeneration capacity; and - remove a limited minerals.	- replace cartridge and membrane on schedules.
distillation	- remove most minerals.	- more complex than RO; and - mineral deficiency may be a health concern.
INSTALL A POINT-OF-ENTRY TREATMENT SYSTEM		
	- permanent solution; - produce large quantity of water; - treat water at every tap in whole house; and - efficiently remover arsenic.	- regular maintenance and testing; and - larger capacity comes with higher cost.
reverse osmosis (RO) with pre-oxidation	- remove most minerals; - remove 98% of arsenic; and - easy to service.	- replace cartridges and membranes on schedules; - use copper/lead-free faucets; - use large quantity of water; and - mineral deficiency may be a health concern.
anion exchange	- remove As+5.	- remove alkalinity to increase water corrosiveness.

adsorptive Media: activated alumina, granular ferric adsorption system,	- simplicity; - easy of operation and handling; - regeneration capacity; and - remove a limited minerals.	- replace cartridge and membrane on schedules
iron Oxide Filter	- remove As^{+3}, $As^{+5,}$ iron	- water testing after using this system
DRILL NEW WELL		
	- potentially a permanent solution - low arsenic if investigating before drilling	- no guarantee to have arsenic-free well water because you cannot be sure the new well will be low in arsenic before it is drilled
CONNECT TO PUBLIC WATER SUPPLY OR COMMUNITY WELL		
	- permanent solution	- not always available to access public water supply; - need cooperation between neighbors; and - need to be sure that the community well is not contaminated.

Notes:
1) Treatment devices should have been certified by an accredited certification organization as meeting the appropriate NSF International (NSF)/American National Standards Institute (ANSI) drinking water treatment unit standards for removing arsenic.
2) The effectiveness of a water treatment system depends on how effectively the source water well is maintained and the level of arsenic present in your water.
3) Assessing competing ions like fluoride, iron, sulfate, silicate and organic matter in well water before installing treatment devices. These ions can interfere with arsenic removal.